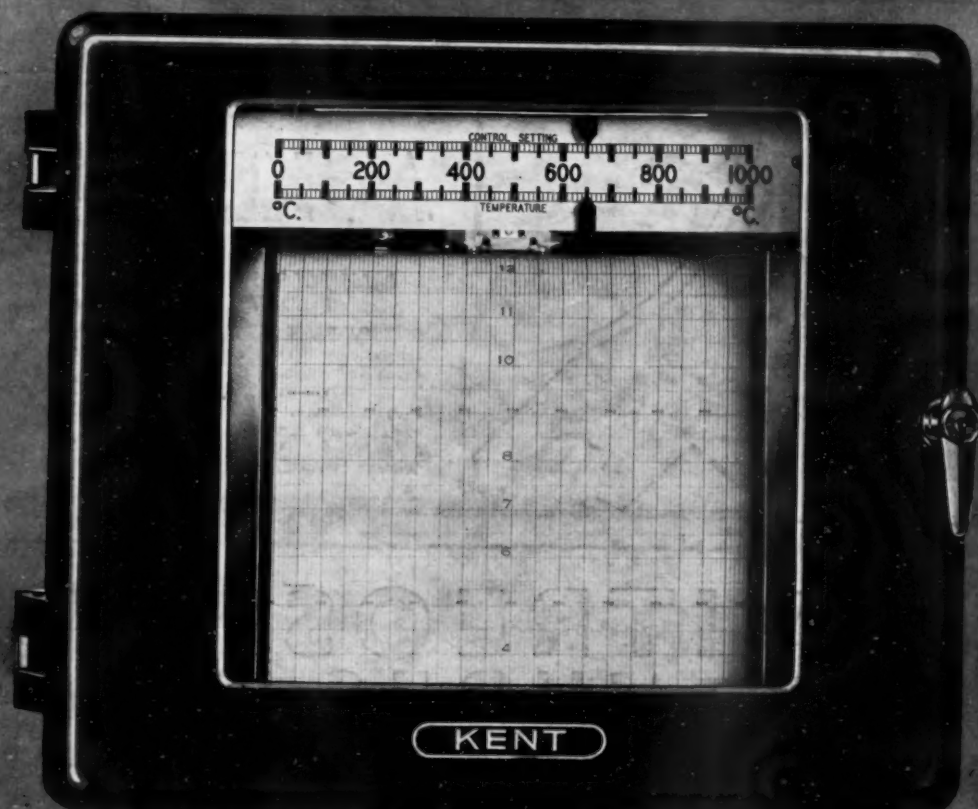# METALLURGIA

THE BRITISH JOURNAL OF METALS

JAN 6 1940

KENT

THE MARK II MULTELEC FOR STEELWORKS

ROOF TEMPERATURE CONTROL OF O.H. FURNACES.

With the Multelec a modern furnace can be driven really hard, yet with much longer time between overhauls. Single-point and three-point Recorders are available. The maximum roof temperature can be controlled automatically with the single point instrument, while both models can be fitted with alarm contacts.

> **TEMPERATURE RECORDER ON EACH O.H. FURNACE.**
> In the absence of automatic control a six-point Multelec Recorder on each furnace gives the following measurements—all of which are essential.
> Air Checkers, Left. :: Gas Checkers, Left.
> Air Checkers, Right. :: Gas Checkers, Right.
> Difference-of-Temperature:: Waste Gas Temperature.
> The Difference-of-Temperature Recorder can be fitted with visible or audible signals giving correct time for reversal.

TEMPERATURE CONTROL OF RE-HEATING FURNACES, SOAKERS, ETC.

A full range of thermocouples or pyrometers and control units for all conditions is available. The various aspects of temperature measurement and control are very fully covered by the sturdy and sensitive Multelec, which, although it detects 1/1000 in. of galvanometer movement, has such a powerful relay action that it cannot be restrained by hand.

GEORGE KENT LTD., LUTON, BEDFORDSHIRE. London Office: 200, High Holborn, W.C. 1

GEORGE KENT

METALLURGIA

The British Journal of Metals
(INCORPORATING THE METALLURGICAL ENGINEER.)

PRINCIPAL CONTENTS IN THIS ISSUE:

Subscription Rates throughout the World - - 24/- per annum, Post free.

METALLURGIA

May we take this opportunity of conveying to all readers our hearty Greetings for the Festive Season and Best Wishes for the Coming Year

1930-1940
A Review of British Industry

IT is over ten years since the first issue of METALLURGIA was published, and it seems opportune to review trade fluctuations and technical developments during this period, because it has proved one of the most complex periods through which British industry has passed. The Great War hastened evolutionary processes and was responsible for the industrialization of countries that had previously been predominantly agrarian, which completely upset the balance of industry and trade, and brought a world slump. In 1930, for instance, Britain was spending over £100,000,000 a year in the relief of unemployment. Economic rather than political considerations were involved. Apart from the merits or demerits of protection, there was the phenomenon of so-called free-trade England suffering as acutely as highly protectionist America, with its unparalleled natural resources.

Many were the statements made regarding the causes of the depression then being suffered by this country. The most insistent of these included obsolete equipment in our works, inefficient organisation and management, over-production, etc., but there was a tendency to overlook the lessons of history. Such problems as reparations, war debts, tariffs and monetary policy brought about a world crisis in 1931, and caused Britain to abandon the gold standard, and, subsequently, to accept the principle of protection for her industries.

Under the stress of adversity the world moved gradually towards a sounder and more orderly economic system. Despite the reactionary tendencies of Germany, Italy, and, in some respects, Russia, which fostered a policy of economic nationalism, a greater appreciation was manifest that far more questions were of international concern than was previously recognised, and, in consequence, there was a growing acknowledgement of the interdependence of trade, national and international. America, which is in a better position to be self-supporting than any other country, showed by her "new deal" that economic nationalism could not be supported, that the collapse of international trade which ultimately results, means idle hands, still machines, ships tied up in docks, and despairing firms and households.

Britain's dependency on export trade made her peculiarly vulnerable to obstacles such as high tariffs and currency chaos. The world's industrial demand had changed, in particular, that for Britain's staple products, but, in spite of many handicaps, this country has gone far in adapting her industrial life to the changes which have taken place. Changes, which in other countries were accompanied by confusion and violence, have taken place here almost imperceptibly by slow, sure and peaceful processes. Britain has shown remarkable resilience during the times of stress, the credit for which is largely due to the commonsense and steadfastness of her people, but

there is abundant evidence that her political, financial and social institutions have proved themselves more stable and yet more adaptable.

Rationalisation of various industries was soon recognised as essential, and was tackled with commendable energy. Schemes for re-organisation were undertaken even in the throes of a world price slump. The obstacles to the re-organisation of the iron and steel industry, for instance, appeared to be insurmountable and, at one time, the prospects of success did not seem good, but with the acceptance of protection which ultimately resulted in a $33\frac{1}{3}\%$ tariff on imported iron and steel, considerable impetus was given to the re-organisation of this and other industries, the beneficial results of which have been seen during the last few years, and particularly now that a national emergency has again arisen.

While re-organisation of industry was in progress, the Government with considerable foresight, was developing old and opening up new channels for international trade. The results of the Ottawa Conference, for instance, though they did not make Empire trading the success it ought to be, did, nevertheless, achieve a degree of success which facilitated economic development within the Empire. Later came the long-awaited World Conference, at which were delegates from 66 nations. The deliberations at this conference were primarily devoted to prices, currencies and abnormal restrictions of trade, and it was thought that they would assist us in restoring international, industrial and commercial activity to a condition commensurate with material progress. It is probable that too much was expected from this conference, and expectations were unfulfilled, but it is probable that, at least, some of the reciprocal agreements which this country made with several countries, and which have been so very valuable, were initiated at this conference.

With the rapid development in industrial organisation, during the period under review, scientific and technical progress has been an outstanding feature. It has led to spectacular achievements and amazing speed records on sea, land and in the air, greatly increased the quality of British products, and increased the capacity of industrial organisations. Evidence of this progress in a few metallurgical fields is given by authorities elsewhere in this issue. But the progress which has resulted from the rapid development in industrial organisation and the technique of production has raised many other problems that are not easy of solution, notably is this true of the problems associated with management. The structure and operation of the modern works organisation are highly complicated, and it is becoming increasingly necessary that the management and administration staffs should be fully qualified to understand their complexities, maintain the delicate structure and guide the operations of the organisation along successful and profitable channels. It was with this object that we commenced the publication of a series of articles on industrial management and production control, the twelfth article of which is published in this issue. Much as we may be tempted to extol the efficiency of our scientific and technical workers, the improved skill of our operators and the increased production now possible, as a result of modernised works and new plant and machinery, unless the energies of the workpeople are directed along profitable paths their potential value is not effectively employed.

Gradually the world's economic difficulties became adjusted to changes, and a forward movement from the bitter and cruel years of depression began to take form.

Very quietly at first, but with gathering momentum the trade channels opened and the efforts made in this country, during the stress of adversity, to restore British prestige politically, economically and industrially, resulted in increased trade, and by May of this year a new high record had been established in the number of employed. The recovery had become so great that a condition of industrial boom was claimed to exist. All industries and districts shared in this improvement, and it was confidently asserted that the boom would continue throughout the coming year, but the international outlook remained unsettled, and war in Europe, which seemed inevitable, despite the peaceful efforts of this country in striving for the maximum human freedom and material progress, again involved us. Abnormal requirements for war purposes have intensified industrial activity in all districts, and some time has been occupied in adjusting production to the system which gives priority to Government orders. This adjustment to war-time economy has resulted in an increase of un-employed, but there are indications that this unfavourable development is only of a temporary character, that, as adjustment proceeds, labour will become increasingly scarce. It is noteworthy that the disciplinary action of years of bitter experience seems to have been effective, since some consideration is already being given to the degree of re-organisation of industrial plants that will be required after the war is over. Extensions at present contemplated or in progress are being subjected to this consideration.

During the period under review there can be no doubt that the facilities for increasing the fruitfulness of human activity have been greatly augmented, but, at the moment, mankind is denied the opportunity of accepting the gifts this fruitfulness implies. The lessons of the Great War have been forgotten, and man's ingenuity is being directed to the slaughter of peaceful people and to means for check-ing aggressive nations, instead of making the world richer for mankind. In the circumstances, no sane man imagines that he can foretell the future with accuracy. Our best predictions must be more or less sagacious guesses. The reason for this is obvious. We may acquaint ourselves with the forces that are at work in the world, but we can-not estimate either their relative strengths or their per-sistency under changing conditions, and it is on these that their ultimate effect must depend ; conditions are, however, moving steadily in Britain's favour, and the same qualities which overcame the economic problems of the early part of this period and restored her industrial activity, will again prevail.

Tin Released

THERE was greatly increased buying of tin at rapidly soaring prices when the decision was made over the second week end of this month to cancel the maximum price of £230 per ton. For some considerable time the effect of this controlled price has been to divert supplies to other markets, where the price was uncontrolled and caused an undesirable drain on the stocks held in this country. The position became so acute that export licences to the Continent were suspended and the Metal Exchange was rationed to 25 tons per day, though certain producers were able to secure sufficient supplies for their more urgent requirements.

The quota of 120% which was decided upon for the third quarter of the year, failed to ease the position, because the American price remained far above our maximum. In the United States the price is already well over £300 per ton. Sales in the East, during recent weeks, have only been about half what should be forthcoming under the quota arrange-ment, and it was realised that this was due to mines either withholding output, where they were not under contract to sell, or were arranging shipment direct to America.

Scrap Metal

THE recovery of scrap and waste metal, and their use with or instead of metals produced from ores, is sound economics in normal times, but it has a greater significance when a country is at war, and much of its raw materials must be transported from countries over-sea. Much has been said both for and against the use of scrap metal and of primary metal, and there is no doubt that when producers first commenced the recovery of metal from scrap and wastes, there was ample reason for criticism, but at that time operations were of a haphazard character, whereas to-day technical advancement has facilitated the production of reliable secondary metals, and the progress in their use is contributing in the economical use of the world's resources of metals. The constant use and re-use of that part of production which is not dissipated in service is concerned with the prudent use of the world's resources, and it is not surprising that a national campaign is in progress in this country with the object of utilising all the scrap metal available.

In recent years considerable attention has been given to the collection and grading of non-ferrous scrap metal, and a high state of efficiency has been reached in dealing with them. The relatively high market value of these metals has greatly assisted collection and their efficient and economical re-use ; in the collection and grading of iron and steel, however, it is doubtful whether the same degree of efficiency has been applied, and thousands of tons must be lying in and around works and factories which would be a valuable addition to the materials required in the iron and steel manufacturing industries. There is an increasing need for scrap metal of all forms and types, and the co-operation of industry in its collection and disposal is earnestly sought.

An all-line system for the collection and disposal of scrap metal has been put into operation by the London, Midland and Scottish Railway, with a view to giving maximum support to the national campaign for increasing the supply of scrap. Employees of all ranks are being urged to co-operate in seeing that not even the smallest piece of waste metal is uncollected, and a special scrap-bin is now pro-vided at every likely place. A pre-war " comb-out " of the L.M.S. system, instigated by a special committee appointed by the company to exploit the collection of scrap over and above that normally collected, resulted in a yield of more than 100,000 tons of additional scrap, the whole of which has already been disposed of. Included in this 100,000 tons were 600 tons representing the aggregation of small " odds and ends " of metal found lying about sidings and depots, and collected by individual members of the staff.

The scrap metal collected by this company, although principally iron and steel, includes nearly all industrial metals. It originates in the workshops, where locomotives and rolling-stock are built, repaired, and, in the case of obsolete units, broken up ; it also emanates from civil engineering work, such as permanent way renewal and bridge replacements ; and from signal and telegraph work. When the national demand for scrap became intensified the whole line was surveyed with a view to the speeding up of normal collection and accelerating the disposal of assets made redundant by changed economic conditions and technical progress.

When it is remembered that the proportion of scrap iron and steel in the manufacture of steel by the open-hearth process is about 50% of the charge, it will be realised how important is the regular supply of these raw materials. The careful collection of all available scrap by all industries on somewhat similar lines to that adopted by the railway company mentioned, would greatly augment the supply and would substantially reduce the amount which must be imported ; this would release vessels for the transport of other materials, which must be imported, and in doing so would perform an important national service.

Progress in Steel Metallurgy During the Last Ten Years

Dr. W. H. Hatfield, F.R.S.

(The Brown-Firth Research Laboratories).

Tremendous advances have been made during the last decade in ferrous metallurgy, and in this article the author confines himself to the application of general science to metallurgical problems associated with the manufacture of steel and to improvements in materials required for industrial and scientific plants and applications.

IT is somewhat difficult to give, within the limits of this brief article, any adequate picture of the tremendous advances which have been made in metallurgy during the last decade. Despite the very difficult times through which the steel industry passed at the beginning of this period, research activities were continued, thus placing the industry in a position to meet the demands which were later to be put upon it. Advances in metallurgy may be divided into two groups :—

   (I) Application of general science to metallurgical problems.

   (II) Improvements in materials required for industrial and scientific plants and applications.

The work of Hume-Rothery on the theory of alloy systems based on atomic physics, whilst hitherto dealing with other than ferrous systems, is making substantial contributions. For instance, it is shown that valency effects play an important part in the liquidus curve, the solidus curve and the values of the solid solubility of the solute atoms. A great service is being rendered by the National Physical Laboratory in its study of pure iron, and from the results of F. Adcock and C. A. Bristow we are now obtaining a basic knowledge of the properties of this metal. Unless we have a concrete knowledge of the phenomena associated with systems of alloys, built up on pure materials, our understanding of commercial alloys remains incomplete,
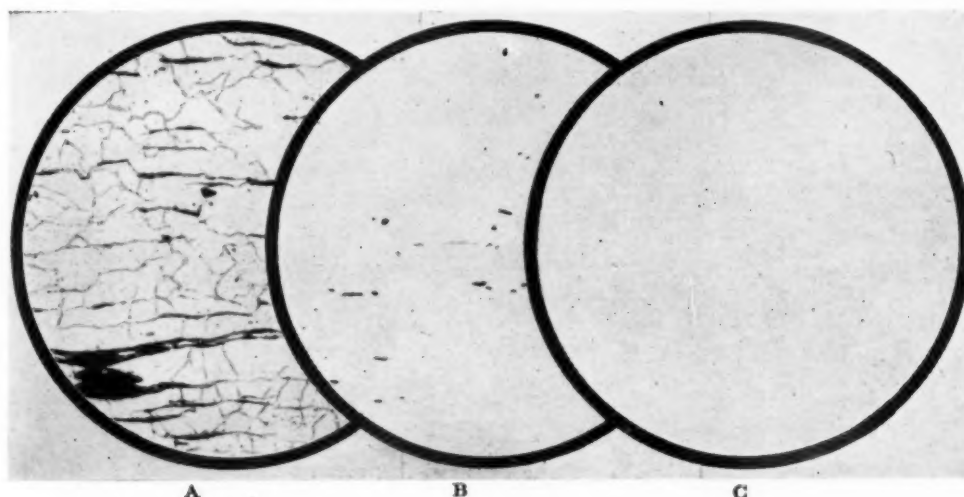
A. Wrought iron × 100

B. Siemens Martins steel × 100.

C. Modern electric arc steel × 100.

Fig. 1. — Progress achieved in reducing the non-metallic " inclusions."

Application of Science to Metallurgical Problems

Under this heading may be quoted the experimental study of the alloy systems. In the first report of the Alloy Steels Research Committee, the author gave a list of those diagrams which can be regarded as reasonably established, although it must be borne in mind that even the iron-carbon diagram is still being worked upon with a view to reasonable finality being obtained. The iron-carbon-chromium alloys have been the subject of many investigations, and the present position as regards this system is dealt with by J. H. G. Monypenny in Section IV of the first report of the Alloy Steels Research Committee. Sections V, VI, VII and VIII of this same report relate to the iron-nickel system, the alloys of iron and sulphur and the cobalt-iron and iron-copper systems respectively. The iron-aluminium system has recently received much attention, particularly in Japan, whilst W. P. Sykes in America has done a considerable amount of work on the constitution of the iron-tungsten and iron-molybdenum systems. Recent German research has included work on the iron-nitrogen system. Among the more important of the many other systems which have received attention of recent years may be mentioned iron-nickel-chromium, iron-manganese-carbon, and iron-nickel-aluminium.

and deductions for future developments may be inaccurately drawn.

The use of X-rays and electron diffraction for the determination of the crystal structures of metals and alloys appears to open up a very valuable field, particularly in regard to the scale-resisting steels.

The application of X-rays for detecting flaws and the use of magnetic devices and electrical resistance determinations for checking the soundness of steel parts has made great advances in the field of non-destructive testing.

A recent and most important development in pyrometry has been that of the " Quick-Immersion " thermocouple for measuring the temperature of liquid steel, both before and after being tapped from the furnace. It consists of a platinum couple, lightly sheathed in silica, which can be plunged into liquid steel so as to give a reading of temperature in a few seconds and be withdrawn intact.

Improvements in Materials

Improvements in materials may be sub-divided into two groups :—

   (a) Improvements in materials by change of manufacturing processes, including melting and forging procedures, heat-treatments, and surface treatments.

(b) Improvements in materials obtained by change of composition.

One of the principal studies of recent years has been the determination of the nature and degree of the homogeneity occurring in large steel ingots as affected by process, composition and conditions of casting, and this may well be considered to come within group (a). A study of the reports of the Heterogeneity of Steel Ingots Committee will show that ingots of various sizes and shapes in various steels have been sectioned and studied. Not only so, but the implications of this heterogeneity in the forged or rolled product has had much attention, and thus, working back, the most suitable ingot as regards process, form and composition can be selected.

One of the important advances relates to the increasing control of the non-metallic " included " matter, which is one serious phase of the heterogeneity of steel ingots. As a result of the reactions of the steel-making process, the liquid steel contains disseminated through it small quantities of oxides of silicon, iron, manganese and other elements, probably almost in the colloidal state, but during the cooling and freezing process these oxides coalesce and orientate themselves in well-defined design ; along with these oxides are sulphides resulting from the sulphur content of the steel. It will be appreciated that such oxides and sulphides will form weakness transversely to the direction of forging and rolling, and any mitigation of the trouble by reduction of the oxide and sulphide content is to be much encouraged. This problem is steadily yielding to inquiry and experiment, although the experimental difficulties are great in that whilst the determining reactions take place at the temperatures of liquid steel, chemical analyses, micro-examinations, and other investigations of the metal and slag must essentially be conducted when the samples have cooled to the ordinary temperature. The compounds in equilibrium or indeed in existence at 1,600° C. in the liquid phases are not necessarily those encountered at 15° C. Solubilities are different, hence, for instance, the difficulties of studying the solubility of gases in such an industrial process. It is important to know the oxygen content and its condition in the liquid steel ; one great step forward has been the development of the vacuum fusion method of determining the total oxygen in the final steel, but we have as yet not quite mastered the technique of determining the form in which the oxygen occurs. It will, however, be realised that the essential knowledge that is required applies to the liquid phase which is another matter. The nitrogen and hydrogen contents of steel are also having much attention, and these, particularly the hydrogen content, may prove of consequence ; the content of hydrogen in steel in the finished state bears little relation to its solubility in either the liquid phase or the recently frozen condition. Largely based upon empirical deductions, progress has been made. The electrical process of steel-melting permits the closest possible control over the physico-chemical reactions of steel-making, and steel is now being made to a standard of " cleanliness " or freedom from non-metallic inclusions, which not many years ago would have been considered impossible. The micro-structures shown in Fig. 1 illustrate the progress which has been already achieved in this direction.

A modification of the induction furnace, known as the high-frequency furnace, is rapidly superseding the crucible furnace, as it permits of the production of certain qualities of steel containing complex mixtures of alloys of a homogeneity unobtainable in the ordinary crucible process.

Whether the ingot be small or very large, it has to be heated to a sufficiently high temperature for forging and/or rolling. Also, steel in varying mass has to be reheated and cooled in the heat-treatment processes, such as annealing, hardening, tempering and stress-annealing. Thus, much research has of late been devoted to studying temperature gradients within the mass with different rates of heating and cooling, the reason being that temperature gradients produce internal stresses under certain conditions high enough to produce rupture, and, even when of a much lower order may in part be permanent in character. Data on these researches are included in the reports of the Alloy Steels Research Committee.

As regards surface treatment, the Shorter Double Duro process is a precision method for local hardening, in which the heating of the steel by an oxy-acetylene blowpipe and the rapid cooling of the heated surface are mechanically controlled. Another recently developed method for local hardening is the Tocco process, in which local heating is effected by internal molecular friction, due to rapidly alternating eddy currents. Parts such as crankpins can be heated to a sufficient depth for hardening in 4 to 6 seconds. Quenching is effected by water spray under pressure.

The use of controlled atmosphere furnaces to avoid deterioration of surfaces is exemplified by the development of the bright annealing process in which surface oxidation of the steel is minimised by the use of an atmosphere of reducing gases.

Among (a) improvements in materials obtained by change of composition, perhaps the most outstanding achievement of recent times is the development of the rustless and heat-resistant steels. In 1913 Brearley had shown that a stainless knife could be made by hardening and tempering a steel containing 13% of chromium. This had led to the search for steel which was rustless in the ductile condition when it was found that a chromium content of 18%, coupled with a nickel content of 8% and a low carbon content, gave what appears, even to-day, to be the optimum combination of these elements. If in this class of steel, however, the carbon content was rather high, or if after softening the steel was submitted to welding, the steel was susceptible to corrosion at the grain boundaries and the intercrystalline attack resulting from contact with certain corroding media was of such a nature that the crystals of the metal fell apart. Since that time it has been determined by research and proved in practice that if the carbon be kept below a certain value, or if tungsten and titanium are added to such steels, the material is immune from this phenomenon. Other modifications have been developed to meet particular conditions of service. For example, molybdenum may be added where resistance to certain acids is essential. Where maximum ductility is required, as, for example, in the manufacture of hollow-ware, the chromium and nickel contents are so modified that the steel contains about 12% of chromium and 12% of nickel.

The heat-resisting steels and alloys known to-day are nearly all of recent development. Very broadly, they can be classified in the following groups :—

A. Plain chromium steels (12–30% chromium).
B. Silicon-chrome steels.
C. Austenitic chromium-nickel steels—chromium and nickel each up to 20%, with or without additions of tungsten and titanium.
D. Higher nickel-chromium alloys—e.g., 60% nickel—20% chromium.

In modern engineering these various types of steels are greatly in demand for such purposes as aero engine valves, grates, fire-bars, superheater tube supports, fans, dust extractors and soot blowers.

As regards new high-tensile alloy steels, greater service for highly stressed structural parts, such as crankshafts, connecting rods, etc., has been made possible by the modification of the 3½% nickel-chromium steels. These modifications have included the addition of molybdenum and vanadium, and values of over 100 tons per sq. in. tensile strength, with relatively high ductility and impact, as well as high-yield ratio, are consistently obtained. It should be stated that such steels demand the best knowledge of the steel-maker both in manufacture and manipulation.

The treatment of tool steels and the development of high-speed steels are two other subjects upon which a considerable amount of work has been done.

Nitralloy steels have been considerably improved since the nitriding process was first developed and the steels in general use at the present time contain from 2 to 3% chromium and about 0·4% molybdenum. Nitralloy has many applications, including air-screw shafts, cylinder liners, brick press plates, pneumatic hammer parts, and other hard-wearing details.

The range of possibilities for the design of permanent magnets has been greatly extended by the introduction of carbon free alloys of the precipitation hardening type. Such alloys include the new K.S. steel, containing 10 to 25% of nickel, 15 to 30% of cobalt, and 8 to 25% of titanium, possessing a remanence of the order of 7,000 gauss with a coercive force of 900 oersteds. The Mishima alloys contain 20 to 30% nickel, and 9 to 12% aluminium, the balance being iron. These possess a coercive force of up to 700 oersteds with a remanence of 11,000 to 7,500 gauss. Horsburgh and Tetley studied the addition of cobalt to the nickel-aluminium-iron alloys, and finally decided to add copper also. A magnet comprising 18% nickel, 10% aluminium, 12% cobalt, 6% copper, and 54% iron, is claimed to show a coercive force of 540 oersteds with a remanence of 7,200 gauss.

The demand for steel having a high coefficient of thermal expansion comparable with that of aluminium has been met by the production of a special steel containing approximately 0·5% carbon, 4% manganese, 11% nickel, and 3% chromium, which was immediately covered by an Air Ministry Specification. This steel also finds application as a high yield-point non-magnetic material for electrical work.

Cast irons with tensile strengths of about 30 tons/sq. in. have been produced during the last few years. This has been achieved principally by the control of the size and quantity of the graphite. With regard to heat-resisting cast irons, the British Cast Iron Research Association has developed a ferritic cast iron containing about 6% silicon, with low carbon and fine graphite which possesses marked resistance to growth and scaling whilst the austenitic heat-resisting irons are a marked advance in the production of relatively heat-resisting cast irons. These irons are also corrosion-resistant.

Fig. 2.—A hollow-forging 50 ft. long and 6 ft. internal diameter forged from a solid mass of 170 tons of steel.

One of the most important developments of recent years has been the evolution of the sintered hard metal carbides. They possess remarkable hardness and are used for dies; for machining all types of materials, such as cast iron and steels and non-metals, such as hard rubber and porcelain; and for wear-resistant parts.

Perhaps one of the most complex studies is that of the changing properties of steel with varying temperature. But quite clearly, assuming, as is the case, that the properties of steel do change with temperature and also in different degree with steels of different composition, it is of the utmost importance to the engineer that he should know the stresses the material will withstand under such changing and different conditions. Therefore the initiation of the study of the phenomenon of creep at elevated temperatures has been one of fundamental importance, since permanence of form and dimension, except for elastic deformation under service stresses with a practical absence of plastic deformation, is essential for modern mechanism.

Journal of the Institute of Metals

Vol. LXIV, 1939.

THIS volume, recently published, is of considerable interest and value, since it contains full reports of two important discussions which took place at the general meeting of the Institute, held in March last. Two of the papers published in this issue are from America, while a third is by two Australian authors. There are also eight other papers, all of the high scientific standard which the Institute requires, scarcely one of which can be regarded as of purely " academic " interest; contributions to discussions are also included, many of which are by leading continental metallurgists.

Of the two general discussions mentioned above, the first concerned the effect of work on the mechanical properties of non-ferrous metals, which centred chiefly round a paper by that eminent metallurgist, Professor Sachs, entitled " Some Observations on the Forging of Strong Aluminium Alloys." One of the contributions to the discussion was deemed of such importance that its author, Dr. L. Frommer, was asked to remould it in the form of a paper, and as such it now appears with the title, " The Estimation of Cold Work from X-ray Diffraction Patterns." It is illustrated by a unique series of X-ray photographs and expounds clearly a technique which is only just being developed, but which will in the near future undoubtedly become of first-class importance.

The other discussion took place on the industrial application of spectrography in the non-ferrous metal industry,

and was introduced by Mr. F. Twyman, F.R.S., a pioneer of spectrography in this country. Among the speakers who followed were a number of analysts from outside the membership of the Institute who were invited so that the discussion should be a comprehensive, as well as authoritative, survey of the most up-to-date practice. Among many interesting contributions, two may be mentioned: Dr. Frommer describes the large-scale control of light-alloy production by the spectrograph, while Professor Breckpot deals at length with current Belgian practice.

Probably the most striking feature of the papers is their practical character; several describe researches arising from actual problems, such as those on " The Elastic Properties of Some Anti-Friction Alloys at Room and at Elevated Temperatures," and " The Influence of Static Stress and Heat-treatment on the Intercrystalline Corrosion of Some Wrought Aluminium Alloys," while the remainder clearly have some potential practical importance. The creep of lead and its alloys, described by Professor Greenwood and Mr. Worner, is a very important factor in the application of the metal, while the question of the vapour pressure of zinc in brasses has a direct bearing on the bright annealing of these alloys. The volume is completed by a reprint of the May Lecture, entitled " The Photographic Emulsion and its Contribution to Science and Industry," which was delivered by Dr. Olaf Bloch.

Copper-Rich Nickel-Aluminium-Copper Alloys

Part III.—Effect of Heat-Treatment on Microstructure

THE effect of the heat-treatment on the hardness and electrical resistivity of the copper-rich alloys containing up to 10% aluminium and 10% of nickel has been reported in Part I.[1] For that study some 56 cast and extruded alloys were examined. The results indicated that above 800° C. all the alloys consist of uniform a solid solutions. They revealed the approximate limits of the a solid solution, while the manner of the changes in properties at lower temperatures implied precipitation of new phases, the origin of one lying in the direction of the nickel-aluminium binary system. Work on these phase changes was described in Part II,[2] in which it was shown that at low temperatures two phases of the nickel-aluminium binary system—namely, the components NiAl and θ (Ni₃Al), take some copper into solid solution, and in these forms—i.e., as NiAl solid solution and θ (Ni₃Al) solid solution—extend their phase formation influence right into the copper corner of the ternary diagram to compositions of the order of only 3% nickel, with 3% and 1% aluminium respectively. Part III[3] of this study is an amplification of the observations of the previous part, linking up the microstructures observed after quenching and tempering treatments with those obtained

As a result of these investigations it is concluded that in the copper-rich alloys the limit of a solid solubility decreases with fall in temperature, and results in the rejection of the two phases θ and NiAl, either singly or, within a very limited range of composition, together. Certain alloys, such as that containing 6% nickel and 6% aluminium, are hardened by precipitation of the NiAl solid solution phase from the solid solution, which phase also causes hardening of brasses containing 10–30% zinc with 6% nickel and 1·5% aluminium.

Alloys containing a relatively small percentage of aluminium and a varying nickel content owe their susceptibility to heat-treatment to the breakdown of the a solid solution, to produce θ (Ni₃Al). The complexity of the mechanism of breakdown is indicated by the microstructures obtainable on various heat-treatments. These are : (1) Recrystallised stable " ragged " grain structure as developed by quenching and tempering treatments : (2) lamellar separations of a and θ in eutectoid form, accompanied by recrystallisation of the a matrix. This structure is developed by slow cooling from the solution temperature at the rate of about 33° C. per day from 700° to 600° C. ; (3) the trefoil precipitate of θ in a obtainable on cooling the alloys very slowly at about 10° C. per day from 700° to 600° C.

Attention is directed by the author to the various copper- and nickel-rich alloys of commercial interest within the ternary system. It is stated that aluminium bronzes have been notably improved in their mechanical properties by the addition of 2–3% nickel, and this improvement is probably partly due to precipitation of the compound NiAl, which restricts grain-size, and also, in the 10–12% aluminium bronzes, to the addition of nickel, which suppresses the breakdown of the β on quenching, so that better physical properties are obtained on tempering.

Alloys containing 4% each of nickel and aluminium are used abroad, and although they find favour primarily because of their ready workability and general resistance to corrosion, yet they may be hardened on quenching and tempering by the precipitation of the NiAl solid solution from the a phase.

The copper-rich alloys, which are readily workable and give the maximum increments on hardening, are those where the ratio of nickel to aluminium is 4 : 1, for nickel contents up to 15%. The alloy used at present, due chiefly to the ease with which it may be fabricated, coupled with its good temper-hardening properties, is the alloy containing 6% nickel and 1·5% aluminium, the hardening being due to a form of recrystallisation of the a matrix accompanied probably by incipient precipitation of θ.

The alloy of corresponding composition developed in the brasses is that containing 72·5% copper, 6% nickel, 1·5% aluminium, and 20% zinc, but here the constituent which separates on temper-hardening is NiAl solid solution.

The variable heat- and corrosion-resistant properties of the cupro-nickel alloys are well known, Monel metal being outstanding in this respect. Its properties at high temperatures are, however, considerably improved by the addition of 3·5% aluminium, together with other minor additions. Similarly, the properties of a 70 : 30 cupro-nickel alloy may be improved by the addition of 1·5% aluminium. In both these cases the presence of aluminium leads to the separation of the θ constituent on temper-hardening or exposure to temperatures of the order of 400°–600° C. for prolonged periods.

Alloys of Magnesium Research

Part IX.—The Constitution of the Magnesium-Rich Alloys of Magnesium, Aluminium and Silver*

THIS is a report of part of the investigation of the constitution and mechanical properties of magnesium alloys which is being conducted at the National Physical Laboratory under the direction of Dr. C. H. Desch, F.R.S., for the Metallurgy Research Board of the Department of Scientific and Industrial Research.

In an early part of this research (Part VII) it was shown that the addition of small quantities of silver to aluminium-magnesium alloys improves their mechanical properties under certain conditions. The constitution of these alloys had not previously been investigated, and an investigation of the system was therefore undertaken. Originally, it was intended to restrict this investigation to alloys containing more than 50% magnesium, but it was soon realised that in order to understand fully the constitution of these alloys it was necessary to go further into the diagram than this. The constitution at this point is very complicated, and although considerable progress has been made in its elucidation, it was realised that much more work would have to be devoted to it before the whole constitution of the phase fields in contact with the ternary eutectic prism was fully understood. As the limits of this prism and of the magnesium solid solution (a) volume had been nearly completely studied at this stage, and as this part of the work was of more immediate practical importance, it was decided to complete it first.

This has now been done, and the results of the investigation on the constitution of the alloys of magnesium with aluminium and silver are reported in this paper. The research included alloys up to about 40% of aluminium and 50% of silver. It has been determined that a ternary eutectic is formed at 403° ± 1° C., having a composition of magnesium 52·8, silver 28·2, aluminium 19·0%. Contour plans of the liquidus, secondary separation, solidus and solid solubility surfaces are reproduced, as well as a number of vertical sections through the constitution prism in the neighbourhood of the ternary eutectic limits. Silver up to 5·2% is soluble in the aluminium-magnesium solid solution at the ternary eutectic temperature, and does not appreciably alter the solid solubility of aluminium in magnesium. Aluminium up to 8·8% is soluble at the same temperature in the silver-magnesium solid solution, but it greatly reduces the solubility of silver in magnesium. The addition of the third component to either of the binary systems increases the steepness of its solid solubility curve.

Personal

Mr. John S. Perrett has been appointed by the Carborundum Co., Ltd., as grinding wheel representative on the North-East Coast, in succession to the late Mr. W. R. Hill.

1 W. O. Alexander and D. Hanson. *J. Inst. Metals.* 1937. **61**, 83.
2 W. O. Alexander. *J. Inst. Metals.* 1938. **63**, 163.
3 W. O. Alexander. *J. Inst. Metals.* Vol 6, Part 10, 499, (October, 1939.)

* J. L. Haughton. *J. Inst. Metals.* 1939, 65. (Advance copy.)

Non-Ferrous Metallurgy
1920-1940

By Frank Hudson

WITH the far-reaching events of the last three months fresh upon our minds those of us connected with the non-ferrous metals will look back over the past ten years, and find much for thought.

In the autumn of 1929 the Institute of Metals ably led by Dr. W. Rosenhain celebrated their coming of age in a meeting held at Düsseldorf, as guests of the Deutsche Gesellschaft für Metall-kunde. Participating in the official welcome was Mr. Keith Jopson, M.B.E., Acting British Consul-General at Cologne, who spoke these words : " We have learned many lessons since the war, not the least of which is that in this close-knit family of nations no one nation can achieve prosperity at the expense of others. The economic well-being of the one is irrevocably bound up in the well-being of the whole. And, therefore, I feel that we may look with great satisfaction upon this meeting as a very hopeful sign of the times—a sign of in-creasing co-operation in the economic life of our two great nations." To-day, looking back over the years to that autumn in Düsseldorf one experiences two disappointments. Firstly, that subsequent events in Germany did not lead to the co-operation all would have welcomed, and, secondly, to the loss experienced by the non-ferrous industry in this country by the death of Dr. Rosenhain on March 17, 1934.

British non-ferrous interests have, however, steadily prospered during the last decade from both the scientific and industrial points of view.

Progress has been exemplified by the stabilizing at economic level of raw material prices coupled with the increased demand for finished and semi-finished products. Unemployment has been de-creased, more money has been put into circulation, and successful trade drives instigated both at home and abroad. Persistent efforts have been made to demonstrate the quality of British products to the world at large for service on sea, on land and in the air. Record-breaking achievements have been of no little value in this latter direction, and we have cause to be proud of the success which has crowned the efforts of men such as Sir Malcolm Campbell and John Cobb, in attaining speeds this year of 141.74 and 368.85 miles per hour, respectively, on water and land. Less spectacular achievements, but none the less important, are apparent in the regaining of the Blue Riband of the Atlantic by the " Queen Mary," in 1938, the marked increase in speed and comfort of passenger rail traffic evidenced by such trains as the " Silver Jubilee," " Coronation Scot," etc., and the inauguration of a regular Trans-Atlantic air service. In all these developments non-ferrous metallurgy has played an important part, and no little credit is due to the efforts during the past ten years of the Research and Development Depart-ment of the Mond Nickel Company Ltd., the Inter-national Aluminium Bureau, the British Non-Ferrous Metals Research Association, the Inter-national Tin Research and Development Council and the Copper Development Association for the assistance they have rendered industry.

Light Alloys

OF all the non-ferrous metals in the period under review, most outstanding progress has been made in connection with the alloys of aluminium and magnesium. It is significant to note that the Autumn Lecture to the Institute of Metals given at Düsseldorf in 1929, by A. G. C. Gwyer was entitled " Aluminium and its Alloys," whilst the subject, " Aluminium and Highland Water Power," was treated on a similar occasion this year by W. Murray Morrison. In the interim period more lectures and articles have been presented to technical associations and the Press dealing with one aspect or another of light-alloy practice than any other single non-ferrous metallurgical subject. If one were asked as to the reason for this progress the answer is still the same as that given by Dr. Gwyer ten years ago, " to the enormous strides which the development of modern transport has made—a development which has, on the one hand, caused engineers to explore all possible avenues for reducing weight, and, on the other, metallurgists energetically to search for new alloys and to try to improve the older and longer-known ones." No completely new light alloys have been discovered of any commercial importance during the past few years, and nearly all activity has been con-tributed to improving existing materials and technique to meet the ever-changing problems of the age.

Progress in the air has been particularly phenomenal. One has witnessed the successful evolution of the all-metal plane in which structural members and fittings are com-posed of one or other of the Duralumin or RR type of alloys with wing and fuselage coverings in high tensile material coated with pure aluminium of the Alclad type combining high mechanical strength with corrosion resistance. Alclad sheet materials are particularly valuable for covering large surface areas susceptible to corrosion, the alternative being protection by anodic methods, a further development of recent years. Mention should also be made of the introduction of retractable under-carriages and the variable-pitch propeller, the gear-box of the air, the success of which has depended to a great degree on either aluminium or magnesium alloys. Engines, too, have been enormously improved. Power units to-day of similar outward appearance and size to their prototypes of five or six years ago are delivering twice the horse-power, an achievement obtained only after modification or improvement of nearly every major component. In the case of high tensile light alloys this has been met by improved fabrication methods and the modern tendency is for such highly-stressed parts as cylinder heads, crank-cases, pistons, etc. to be made in the form of forgings or stampings, rather than as castings. It should, however, be noted that the quality of castings has been enormously improved following the introduction of X-ray examination in the foundry. Space does not permit mention of the many light alloys used in industry, except the introduction in 1937 of Hiduminium RR 77, developed for use in highly stressed structural parts. When treated in a suitable manner it has an ultimate tensile strength of between 33 and 38 tons per sq. in., 28 to 33 tons per sq. in. at $0\cdot1\%$ proof stress, 16 to 10% elongation in conjunction with a Brinell hardness value between 160 and 180. In addition to the above, it possesses excellent corrosion and fatigue

Cast aluminium-bronze anchor chain for non-magnetic ship, R.R.S. Research.

resistance, and affords a worthy example of one of the outstanding contributions to non-ferrous metallurgy.

Whilst the air is obviously the natural and most important sphere for light alloys, transport in other fields has also benefited by their use. A review of this nature would not be complete without pointing out the important part played by aluminium-alloy fittings on our crack trains and ships. The high speeds of the *Silver Jubilee*, *Coronation Scot*, and *Queen Mary* would not have been so readily obtained without the saving in weight made possible by such means. Aluminium-alloy cylinder heads and pistons have helped to develop the efficiency of the modern car, and we can now look forward to its use for bearing purposes with the introduction of Rolls-Royce AC 9 material. After exhaustive road tests this alloy, which contains approximately 5·5 to 7·0% tin, 1·5 to 1·8% nickel, 0·6 to 0·9% copper, 0·7 to 1·0% magnesium, 0·15 to 0·3% silicon, 0·2 to 0·45% iron, balance aluminium, has been adopted as standard for big-end and main bearings on the 25-h.p. Rolls-Royce and Bentley engines. From the results so far obtained it would appear that this material has a very promising future in the bearing field.

From the production point of view outstanding metallurgical developments have arisen, particularly in America, with the introducing of the Hazelett Process to the direct manufacture of aluminium strip from molten metal. In this country attention has been devoted to improving foundry technique, particularly as regards the magnesium alloys, degasification methods, and the introduction of the low-frequency electric induction furnace.

Copper and Copper-base Alloys

In the field of copper and copper-base alloys good progress has been made. Published in the very first issue of METALLURGIA there was an article by W. Cullen, with a most significant title, "Non-Ferrous Metallurgy. Can it be Revived in Great Britain ? " This primarily covered factors dealing with metal resources and production of the British Empire, and on looking back over the past 10 years it cannot but be agreed that the answer is in the affirmative. Take, for example, the application of flotation to the concentrating of copper ores. This has resulted in a higher efficiency of recovery in ore dressing—90% instead of 60%—and usually a higher grade of concentrate, 25 to 50% copper, instead of 15%. Other developments of the period in connection with copper production have been the introduction of oxygen-free high-conductivity copper embodying casting in controlled atmosphere, improved water-cooled moulds, better smelting methods and continuous casting methods. At the works of the Ontario

Refining Company, 1936 witnessed the installation of the first electric arc furnace with a rated capacity in excess of 10 tons per hour for the continuous production of tough pitch copper. This is considered to be one of the most important contributions to the art of copper refining for many years. A more recent development of the same company is the manufacture of vertically-cast wire bars with double-pointed ends carefully designed to prevent over-rolling and end-scrap in subsequent operations. In regard to finished copper products reference might be made to the production in this country of Pyrotenax metal-clad cable comprising a copper tube carrying the conductor wires, spaced in a matrix of anhydrous magnesium oxide. The cable is fireproof up to the melting point of copper.

Successful research has improved our knowledge of the fundamentals arising in connection with melting metals. It is interesting to note that 10 years ago it was considered satisfactory practice to employ neutral or slightly reducing furnace atmospheres. Following the pioneer work of Dr. N. P. Allen in this country, and Dr. H. Lepp on the continent, relative to the effect of gases on copper and degasification methods, we now know that the use of reducing or even neutral atmospheres is incorrect, and that best results are obtained with oxidising conditions —a complete reversal of the old ideas. Practical application of these discoveries has led to pronounced improvement of casting quality in a wide variety of alloys, both as regards density and mechanical properties. By carefully eliminating gases from molten copper-tin alloys, Lepp has succeeded in cold rolling on a commercial basis ingots containing as much as 14% tin.

In the brass foundry some attention has been devoted to moulding sand control and production improved by the perfection of centrifugal casting methods and the inception of cement moulding which has been found particularly adaptable for the manufacture of large castings such as marine propellers.

The last decade, too, has witnessed the development of many new copper-base alloys having remarkable properties. The outstanding characteristic in the majority of cases has been the promotion of high mechanical properties and hardness brought about by the addition of relatively small percentages of one or more other elements in conjunction with suitable heat-treatment. Nickel-aluminium brasses of the Kunial type together with the nickel-tin-copper range of alloys are just two typical products out of the many new materials susceptible to such process. Recent investigation has shown that nickel-bronze castings containing 5% nickel, 5% tin, 2% zinc, balance copper, will readily give a tensile strength up to 40 tons per sq. in. with 10% elongation together with a Brinell hardness

Rolling pure nickel radio strip at the works of Messrs. Henry Wiggin and Co. Ltd., Birmingham. The demand for such material has been increased in recent years with the increasing development of radio and television receivers.
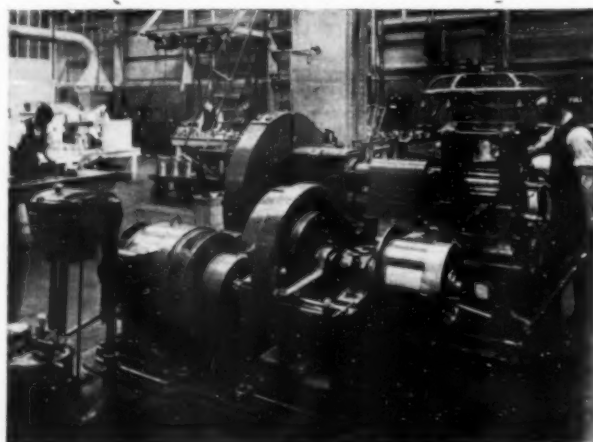
of around 190 after a suitable quenching and tempering operation. Other alloys susceptible to temper-hardening are Kuprodur, containing copper, nickel and silicon, developed for locomotive fire-box purposes—the copper-chromium group—the nickel-aluminium bronzes and copper-beryllium alloys. The aluminium bronzes have long been regarded as an extremely useful group of alloys, particularly as regards corrosion service and satisfactory sources of supply for both fabricated and cast sections are now available in this country to meet the requirements of engineers as well as die-castings for which the alloy is particularly adaptable.

Nickel and its Alloys

Nickel holds a unique position in the metallurgical field as whilst primarily a non-ferrous metal, approximately 65% of the world consumption is taken up by the ferrous industries in the manufacture of iron and steel. During the period under review nickel has, however, also played an increasingly important part in non-ferrous metallurgy. From previous remarks its association in small amounts with the light alloys and the more recent bronze and brass developments will have been noted. In connection with pure nickel and high-nickel alloys principal progress has been made in extending their useful sphere in conjunction with improved methods of production in this country, particularly as regards the supply of extrusions and castings. It would take an article in itself to outline adequately the advances made in the first direction due to the wide variety of application. Pure nickel, Monel, Inconel, nickel-clad steel and alloys of the Hastelloy group are to be found giving excellent service in resisting corrosion in the chemical, paper, textile and food industries and in the power field. Important corrosion research has been conducted during the last few years by both producer and user to assist the selection of the most suitable material to meet particular service conditions. Inconel and allied nickel-chromium alloys have excellent heat-resistance, and the former is now extensively employed for aircraft exhaust manifolds. The " life factor " of the latter group of alloys widely used for domestic electric heating appliances has been considerably improved in recent years. One of the most recent developments is the introduction of nickel powder for use in " powder metallurgy," paint, etc.

From the production viewpoint, particular mention might be made of the introduction of the Monel integral root turbine blade and the advances made in connection with the extrusion of 20% nickel silver sections. " K " Monel and " Z " nickel are the latest additions to the range of heat treatable wrought materials available with high mechanical properties. The properties of the latter alloy are particularly interesting as they cover a maximum strength range of 68 to 100 tons per sq. in. with 20 to 5% elongation on 2 in. with a Brinell hardness between 300 and 450.

All the high nickel alloys retain a large measure of their strength and hardness at elevated temperatures, and accordingly " S " Monel, containing around 3·75% silicon, in conjunction with nickel-copper-tin and nickel-copper-tin-silicon alloys of over 40% nickel are widely applied for steam valve trim. At the present time the properties of these materials at working temperatures are being explored with most astonishing results. From work already completed it is interesting to note that the hardness of " S " Monel, for example, at 1,000° F. is actually greater than Stellite, although the reverse applies at room temperatures.

Miscellaneous Alloys

Coming now to metals in the tin and lead base group the properties of solders have been examined and improvements in tensile strength and in creep resistance obtained by small additions of tellurium. Additions of this latter metal have also been found to improve the mechanical properties of lead pipe. During recent years a large amount of research work has been completed in connection with bearing metals, and investigation has emphasised the
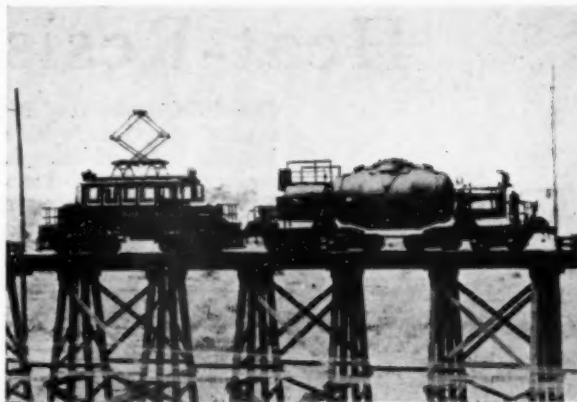
With a metal capacity of approximately 60 tons, moveable holding furnaces, constructed of 1-in. steel plate and lined with magnesite brick backed by insulating fire-clay brick, are being used to transfer molten blister copper a distance of 1½ miles from the smelter converters to the refinery anode-furnaces at the works of the Ontario Refining Company Ltd., in Canada.

surprisingly high stresses set-up as a result of differential rates of contraction between the white metal and the shell on to which it is cast. In other cases failure has occurred through fatigue, and efforts have been made to improve the life of bearings by the development of new materials having higher strength and fatigue resistance under service conditions. It has been found, for example, that an alloy of cadmium with approximately 1·3% nickel, or 2·25% silver, 0·25% copper has improved mechanical properties over material of the tin base type, but tends to be corroded by lubricating oils containing oleic acid. Whilst a great deal of useful metallurgical research has been conducted on bearing problems in general during the last 10 years, more data is still required before any dogmatic views can be expressed on the problem.

Other metallurgical developments of the period 1930-1940 worthy of note are in connection with the manufacture of articles from metallic powder, such as, for example, bearings of the " Oilite " type, and the industrial application of spectrographic analysis.

In conclusion, it can be claimed that the review period covered shows active industrial progress in the field of non-ferrous metallurgy. As to future trends, these will now depend to a large degree upon our war requirements. Research in connection with the host of non-ferrous materials necessary to the Armed Forces, light alloys, bearing problems and those fundamental factors causing mechanical wear, are obvious subjects which will require close attention. One can be assured that the non-ferrous industry will play a vital part in maintaining the efficiency of our fighting machine in many directions, and if past efforts can be used as a guide to the future, there is no need to fear the outcome.

International Electrotechnical Commission

In present circumstances the work of many international organisations has necessarily been curtailed or even suspended. It is to be noted, however, that during the war it is proposed to maintain the Central Office of the International Electrotechnical Commission in London.

It will probably not be possible for meetings of the Technical Advisory Committees to be held during the war, but as much as possible will be done by correspondence with a view to bringing to a conclusion all work which was nearing completion at the outbreak of hostilities. It is felt that the National Committees may like to have the benefit of the work already accomplished, and as many as possible of the draft specifications which have been under consideration during the last year or two will, it is hoped, be issued as Provisional I.E.C. Recommendations. In the meantime, copies of all existing I.E.C. Publications are still obtainable from the General Secretary of the I.E.C., 28, Victoria Street, London, S.W. 1.

Heat-Resisting Steels

The vital importance of developing scientific knowledge was emphasised by Dr. Hatfield in a recent lecture to the Midland Metallurgical Societies. In this abstract is given a brief survey of the effect of a range of temperatures on mild steel, the reduction of strength at elevated temperatures showing the need for special heat-resisting steels which have increasingly developed in recent years. A range of these steels is discussed.

ALTHOUGH when a great war is in progress it is not practicable to continue technical meetings as in time of peace, yet everyone must admit that technical progress comes next in importance to the maintenance of the Forces in the Field. It must be remembered that had it not been for two British chemists, Thomas and Gilchrist, Germany to-day might have approximated more nearly to her former pastoral condition. It was due to these two Englishmen that the basic iron ores of Germany were released, so making possible the great misuse of the powers of metallurgy. Those who were interested in large industrial enterprises were very busy, but it would be appreciated that the development of scientific knowledge is of vital importance during the war and should continue unchecked in order that the country may be in a favourable position for tackling post-war problems.

With regard to heat-resisting steels, it is of value to take a survey of what happened to mild steel over a wide range of temperatures—say from −180° to 1,000° C. Perhaps the outstanding feature, taking for example a 0·25% carbon steel, is the fact that the maximum stress is increased whether the temperatures be raised or lowered from normal room temperatures. What is known as the " blue brittle " zone occurs in such a steel at about 200° C. This phenomenon of the hardening up of mild steel, when heated to approximately 200° C., is well known to investigators, but it is not so widely appreciated by the general industrial world. On heating the steel above this range the maximum strength begins to fall. At 700° C. it is only about 6 tons/sq. in., and the decrease in strength continues as the temperature approaches that at which the steel is hot-worked. At very low temperatures, below room temperature, the maximum strength rises.

In dealing with heat-resistant steels, they should first be considered in the light of their strength at elevated temperatures. This may be viewed either as resistance to stress at certain temperatures with a certain favourable amount of deformation, or alternatively from the standpoint of the deformation produced by a certain stress at a given temperature. Secondly, there is the question of resistance to scaling, and, clearly, a steel which may have a sufficient margin of strength, at a certain temperature, is not of industrial importance if it is subject to severe scaling at that temperature.

Some years ago Dr. Hatfield introduced the austenitic chromium nickel rustless steels into this country, and it was suggested that these steels, which, after cold-working, had a very high mechanical stress, would deteriorate under comparatively low stresses even at normal temperatures, given sufficient time. It was suggested that any steel would flow and permanently deform under any stress, and that the movement could be observed provided the sensitivity of the measurement were sufficiently refined. Consequently, he decided to put an experiment in hand. Nearly eleven years ago, a strip of cold-worked austenitic chromium nickel steel was put under a stress of 25 tons/sq. in. Since that time it has been under constant observation, and measurements of the test-piece had been carefully made month after month. He definitely stated that if any creep whatever had taken place in that time, it was of an order less than one twenty-seven-thousandth-millionth of an inch per inch per hour. In other words,

if a 10-ft. length were placed under a load of 25 tons for 20 years, the actual increase on the total length of the specimen would be less than one-thousandth of an inch. This experiment had finally determined for all practical purposes the permanence of dimensions under ordinary loads of such steels. When a red heat was reached, however, that degree of permanence of dimensions under stress did not hold. An alloy steel at such a temperature under an ordinary tensile test may give a maximum stress of 20 tons per sq. in., but if it was stressed under a load of as little as 1 ton, plastic deformation occurred and may continue for a long period of time at that temperature. It was necessary, therefore, to study the phenomenon of resistance to stress with time, and that value is termed creep resistance.

How is it possible to convert mild steel with little strength at high temperatures to steel with great strength at high temperatures ? This is a very big subject, and one on which an immense amount of literature has been published and a large number of patents taken out. If all these data were tabulated, it would be found that numerous people had suggested that the solution to the problem was to add certain elements in very varying proportions, but it will be appreciated that if all the elements which had been suggested in the patent literature were taken, and each one only varied three times, about fifty million alloys would have to be made. As a result of more restricted experimental working, from a practical point of view, a very satisfactory technology had resulted in the production of steels with excellent heat-resisting properties.

It is not impossible to go through all the work that has been carried out. There is, for instance, a series of steels with a constant carbon content, but with the chromium content varying from nil to 33%. As chromium increases, so does the resistance, and in fact a steel containing 30% chromium shows great resistance to scaling at very high temperatures. A steel containing 13% chromium resists oxidation, but such a steel is not strong at high temperatures, while a steel containing about 23% chromium, 12% nickel, and 3% tungsten possesses great strength at high temperatures, as well as resistance to scaling, but it is obvious that a composition which gives the highest resistance to scaling, does not necessarily possess the highest strength at any specified temperature, and consequently some kind of compromise has to be made. Those interested in supplying steels to work at high temperatures do not expect them to last for 20 years. If they lasted from six months up to two years they would be regarded as a good proposition, and such were our experimental abilities at the present time that details could now be given as to what would happen under given industrial conditions.

As a result of technology, steels are now available which would resist stress with little deformation at high temperatures and which are, at the same time, successfully resistant to scaling. It should be noted that certain alloys can be used up to 700° C., some up to 1,000° C., and others up to 1,100° C. The temperature at which the material is to be used determines the type of heat-resisting steel to be employed. Obviously, if the temperatures in question do not exceed 700° C., it is useless paying for a very rich alloy. It is, therefore, very important that the customer should state the conditions of service when asking for a steel for any specified purpose.

Ten Years' Progress In Cast Iron

By J. G. Pearce, M.Sc., F.Inst.P., M.I.Mech.E., M.I.E.E.

During the early part of the period under review it was confidently asserted that the products of the iron foundry were being displaced by products resulting from rapid developments in other fields. Progress in research has since made great strides forward, and this has resulted in the development of the iron-founding industry which, to-day, is again in the forefront of progress.

IN reviewing progress for the period since the last war the general progress of foundry production is broken by melancholy fluctuations, due to the post-war slump and the coal dispute. For the ten-year period, 1929—1939, however, the former year was commercially quite good and became a standard by which subsequent years were judged, and foundry pig-iron production, for example, did not subsequently reach a comparable output until 1937.

The progress made in research and development can well be judged with reference to specifications, which nowadays so rapidly reflect research progress. In 1928 the first general specification for grey-iron castings, No. 321, was issued by the British Standards Institution. It had three test-pieces and two grades of iron of 10 and 12 tons per square inch tensile strength. In 1938 the specification was issued in revised form with five test-pieces, and was accompanied by another specification for high-duty irons, No. 786, giving three categories of grey cast iron of better quality than those in 321, and going up to a figure of 22 tons per square inch. It is evident that in making it possible for any buyer of castings to demand such improvement in quality, considerable developments must have gone on throughout the industry. The direction this has taken may be briefly noted, and as a necessary factor in controlled production we may note the establishment of recommended methods of sampling and testing, including chemical analysis, microstructure and mechanical tests. Recommended practice is now available in each of these directions, both for process control and for the control of the finished product. Apparatus and methods of testing have also been evolved for the control of moulding and core sands, natural and synthetic.

Foundry Practice

While not spectacular, constant improvement has taken place in foundry practice, with the result that iron castings to-day are more true to design and form, more regular and uniform in properties, and more sound and free from both external and internal defects than ever before. In moulding sand, the cement-sand process has been introduced and the use of synthetic sand, made by bonding clay-free or a low clay-bearing sand with colloidal clay, has been established. Perhaps the most striking change in foundry practice has been the development of mechanised and continuous production, and an enormous amount of ingenuity has been displayed in making such production possible. In this respect, and in the economy of large-scale production, the best British foundries are a pattern to the world.

Melting Practice

While the decade has seen the development both of the pulverised-fuel-fired and the oil-fired rotary furnace, and of the wider application both of the electric induction and arc furnaces and of improved types of crucible furnace to foundry practice, the cupola still remains the universal foundry melting unit. The design has become more standardised and performance can be more accurately predicted. Of the type developed, known as the balanced blast cupola, in which the tuyere air supply is valve-
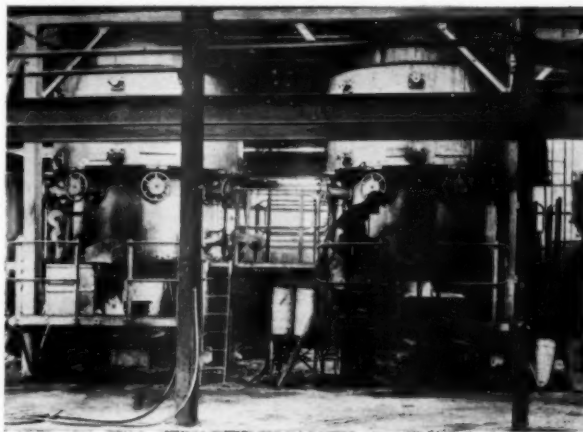
Fig. 1.—Balanced blast cupolas installed at the works of the Austin Motor Co., Ltd.

controlled, over two hundred have been installed in this country and abroad, capable of an hourly output exceeding 1,500 tons. Fig. 1 shows an installation. The hot-blast furnace has also undergone considerable development in the U.S.A., but it cannot be said that the fuel consumptions are better, if as good, as those of the best cold-blast cupolas in this country. A characteristic development with regard to melting practice has been the use of refined pig irons, both plain and alloyed.

Alloy Additions and Heat-treatment

A striking feature of this period has been the enormous amount of both research and development on alloy additions to cast iron. The development began with nickel, by means of which element practically any structural component can be made to predominate in cast iron—pearlite, austenite or martensite,—giving a variety of fractures and properties useful under particular circumstances. Ordinary cast iron is a mixture of ferrite and pearlite, and the achievement of a fully pearlitic structure was the first step in the improvement of the mechanical properties of cast iron. The evolution of austenitic irons, such as Nomag, Niresist, Nicrosilal, is regarded by some as the most remarkable recent development in the metallurgy of cast iron, and these materials have structures and properties different from those of ordinary grey irons, particularly valuable in certain applications, and they employ nickel, copper and chromium to achieve the desired structure. They are soft, ductile and highly resistant to wear, heat and corrosion. The development has continued in respect of such additions as molybdenum, chromium, copper, vanadium, titanium, and to-day what were at one time regarded as comparatively rare elements are commercial additions. Combined with this development has been that of heat-treatment and annealing, by means of which the properties of the best irons may be raised as much as 50%. Another remarkable development has been that following on the use of ladle graphitisers, the first patent in connection with which was taken out by Meehan. Irons made with the addition
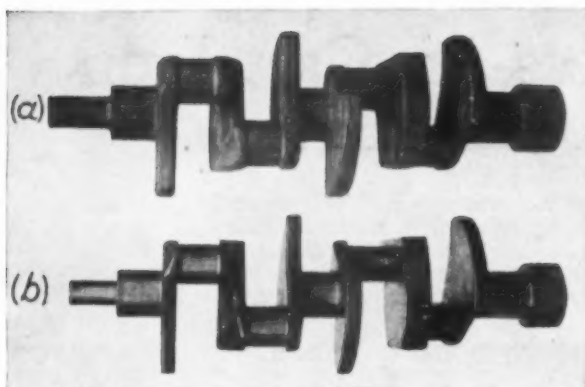
Fig. 2.—Automobile crankshafts.
(a) As cast. (b) After machining.

of such materials are now widely made and used, and have a density and strength which makes them very attractive to the engineer. The process of manufacture consists in running an iron to such composition that for the section intended it is virtually white, and converting this into a dense grey iron by means of a carefully calculated ladle addition to the molten metal. This results in a dense grey iron, and by means of this process the strongest grey irons in the as-cast condition are made, running up to as much as 30 tons per square inch. These ladle additions may also be used in conjunction with alloy additions.

Malleable Cast Iron

The traditional process for the manufacture of malleable iron is well known. In the case of the usual European or white-heart process, a crucible, cupola or air-furnace iron is cast in the white state and annealed in an oxidising ore, to give a structure of pearlite and temper-carbon. In the case of the usual American black-heart process, an iron rather lower in carbon is annealed in a neutral packing to ferrite and temper-carbon. During the decade the ingenuity of metallurgists has been taxed to produce better properties from malleable castings, to reduce the annealing time and to produce any metallurgical structure that may be required to suit the application in view. For practical purposes either ferritic or pearlitic structures may be obtained by either process. It has also proved practicable to reduce the annealing time, and hence delivery time, very considerably, as in the production of so-called short-cycle malleable ; but in some authoritative quarters it is held that the short-cycle material, technically practicable, is difficult to justify commercially on account of the special compositions and special furnace equipment required.

High Duty Irons

The highest strength obtainable from a cast iron is now obtained by casting a low-carbon alloy material in the white state and subsequently annealing it to a pearlite temper-carbon structure, and such materials form a connecting

Fig. 3.—Castings in heat-resisting and ordinary cast iron.

CRALFER   ORDINARY CAST IRON

link between grey iron and malleable cast iron. Strengths of over 60 tons per square inch have been recorded on such material, and special low-carbon alloy irons have been developed and widely used commercially for such articles as automobile camshafts, crankshafts, etc. Fig. 2 shows a commercial crankshaft.*

The use of engineering materials under dynamic, as distinct from static, conditions has shown the engineer that elongation is of less importance than was commonly supposed, and, indeed, in the case of fatigue failure appears of little value. These high-duty irons, used for such exacting services, for example, as crankshafts, are valued for their castability, machinability, high resistance to wear and corrosion, and damping capacity, by which super-imposed stresses in working are absorbed.

Heat, Corrosion and Wear Resistance

The problems of special applications, apart from ordinary engineering use, frequently reduce themselves to heat, corrosion and wear resistance. During the decade the mechanism of failure in each of these cases has been intensively studied, with the result that the user is offered materials likely to withstand the requirements of service. Thus, the ferritic Silal heat-resisting irons, high in silicon, have found a place for themselves, and reference has already been made to the value of austenitic irons. The irons high in chromium (30%) also have special value for heat and corrosion resistance, especially where sulphurous gases are concerned. The roll industry and the crushing and grinding industries are also indebted to special cast irons for wear resistance. The most recent development for heat-resistance is a series of irons containing aluminium, normally about $7 \cdot 5\%$, and known as Cralfer irons. Fig. 3 shows a Cralfer grate alongside a similar, but slightly larger, grate in ordinary iron, each having had the same length of service. The former is practically untouched, while the latter has scaled and warped badly. It will be appreciated that as service conditions vary, so compositions and structures can be varied to give the metal likely to yield the best ratio of cost to life.

Graphite Refinement

The improvement in the mechanical and other properties of cast iron has been due to two processes—the increased strength of the matrix, due to the use of alloy additions, heat-treatment, and to control, leading to a uniform and regular structure of the type desired ; and secondly, the steady reduction in the size of graphite flakes. The graphite structure of irons treated with ladle graphitisers, for example, while of the flake type, is finer than that of irons which have been cast and cooled in the ordinary way. By casting under certain conditions involving rapid cooling, an extremely fine-type graphite is frequently seen in localised areas, and by the process due to Norbury and Morgan it has been found possible to produce this type of graphite, the finest theoretically possible, uniformly throughout a comparatively heavy section. Some interesting speculations have been made as to the reasons governing graphite formation in the flake form or in this fine, so-called supercooled type, and while finality has by no means been reached, it is believed that graphite formation is connected with the presence or absence of non-metallic inclusions. The separation and estimation of these inclusions has, therefore, become a matter of importance, and here again considerable work has been done in cast iron, as it has with steel.

Centrifugal Castings

Reference must be made to the development of centrifugal castings, both for pipes and piston-ring pots and cylinder liners. This special development has also had regard to progress in the other directions mentioned above, and also to the process of nitrogen hardening, by means of which hardness figures of the highest order are now obtained on cast iron.
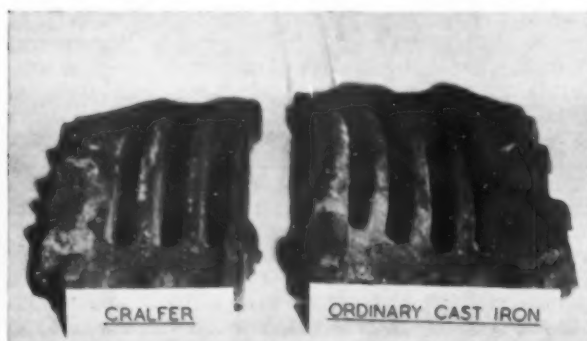
* Reproduced from Gough and Pollard, *Proceedings of the Institution of Automobile Engineers.* Vol. 31. 1937.

Copper and Copper Alloys: a Survey of Technical Progress During 1939

By H. J. Miller, M.Sc.

Progress of an essential practical significance is discussed, attention being directed particularly to fabrication practice ; melting and foundry practice ; the properties of copper and alloys containing tin, zinc, and silicon ; precipitation hardening copper-base alloys ; their conductivity applications ; chromium additions to copper base alloys ; alloys for corrosion service ; production of bearings from metal powders ; and electrodeposition of copper.

SO much metallurgical data is published in the course of a one-year period that it is not easy to make a selection of the material most suitable for inclusion in an annual review which is intended to be a record of progress having an essentially practical significance. The references mentioned have been included for the reason that they provide new information on materials in every-day use, or are technical suggestions of a practical character ; general articles which give convenient and more or less complete surveys of progress in any particular field have also been mentioned in a few instances.

At the time of presenting this review the 'thirties are ending, and a new decade is beginning. This decade will witness the freedom from patent restrictions of many copper alloy groups for which patents were granted in the 'twenties, which was an especially busy period in connection with precipitation hardening alloys. It might, therefore, be anticipated that the 'forties will see more activity as regards some of these alloys, since many consider that the existence of patents has tended to restrict their exploitation. Among the precipitation hardening alloys are Cu-Be, Cu-Ni-Si, Cu-Co, Cu-Cr, Cu-Fe-Si, and a host of others, the discovery of many of which was due to M. G. Corson ; other alloys include the Cu-Si-Mn series.

A noteworthy feature of many recent patent applications is the number which are founded on these older alloys, but contain additions of one or more elements which confer improvements such as refined grain size. Hence, although the lapse of original patents might be said to clear the field, the existence of a large number of recent patents, some of doubtful originality and value, will probably still cloud the issue.

Fabrication Practice

No appreciable changes in fabrication practice have been introduced during the last twelve months, but in any case major developments in plant and procedure require relatively long periods to attain a satisfactory stage of fruition. Two developments which have caused much interest, however, are in respect of carbon arc melting furnaces, and radiant tube gas-fired annealing furnaces. Over the past two or three years carbon arc furnaces for the melting of copper have been proved an economical proposition, first in one of the Canadian refineries for the melting of large quantities of cathode copper, and more recently in small units for melting quantities of the order of 10 cwt. upwards ; the latter sizes thus appeal to small fabricators concerned with billet production, and units of this type have been installed in this country for the routine casting of billets required for the manufacture of copper tubes.

Radiant tube gas-fired furnaces have now reached such a stage of development that it seems possible they may supplant electric resistance annealing equipment, at least for certain phases of annealing operations. Robiette[1] has reviewed this development recently.

The extrusion of alpha nickel silvers containing about 20% nickel has been discussed for a considerable period,

although hitherto there has only been a limited production of extruded sections. During the past year there has apparently been a further advancement, and many large and complicated sections were manufactured for the British Pavilion in the New York World's Fair.

The direct rolling of metals from the molten state, on which considerable effort has been expended during the last ten years, seems to have been abandoned as far as copper alloys are concerned. Experience to date has been summarised by Hazelett,[2] who, of course, has been mainly instrumental in developing this method of fabrication. Another useful survey was provided by Mort.[3]

A British patent[4] has been granted in respect of the German Junghans process for the direct casting of billets. An essential feature of this method is the reciprocal motion which is imparted to the bottomless water-cooled mould to prevent adhesion of the metal to the mould walls. It is understood that in U.S.A. this method has been applied to the casting of copper billets, but further information is not available.

The pickling of copper alloys is a matter which has in the past received little consideration by investigators, although there is no doubt that the subject merits greater attention. Loutrel[5] has experimented with a ferric sulphate bright dipping solution for the treatment of brass, and this appears to have many advantages over bichromate pickling solutions ; however, in view of the conventional idea that iron salts give rise to red staining trouble on brass, industrialists will probably be rather chary of adopting solutions of this type.

Non-ferrous Melting and Foundry Practice

Increasing attention is now being given to the important influence of melting conditions on the properties of cast products. In general, an oxidising furnace atmosphere, rapid melting and an avoidance of overheating so as to minimise absorption of hydrogen are recognised as the desirable factors, and these are agreed to be of special importance with bronzes. As has been so very well demonstrated by Lepp during the last few years, the properties of copper-tin alloys prepared and cast under controlled conditions differ remarkably from the normal products. For both copper-tin and copper-tin-nickel alloys, Hudson[6] has published recommended production methods, the main feature of which is the addition of oxidising compounds after melting, and prior to final deoxidation, so as to reduce the gas content of the molten metal and thereby give sounder castings ; cuprous oxide was suggested as being satisfactory, but alternatives were manganese dioxide or certain proprietary oxidising fluxes. The oxidising materials are best added to the molten metal in small quantities, making successive additions until the effervescent type of reaction, due to hydrogen reacting with the oxide, ceases. Chadwick[7] employed a similar technique in

1 A. G. Robiette. *Metal Industry.* 1939. 55, 365.
2 C. W. Hazelett. *Mech. Eng.* 1939. 61, 823.
3 E. A. Mort. *Metal Industry.* 1939. 54, 41.
4 S. Junghans. Brit. Patent 505,075.
5 L. F. Loutrel. Amer. Electroplaters' Soc. Preprint (also *Metal Industry.* 1939. 54, 587.)
6 F. Hudson. *Found. Trade J.* 1939. 60, 265 and 287.
7 R. Chadwick. *J. Inst. Metals.* 1939. 64, 331.

his research on the fabrication of copper-tin alloys, as considered in another section of this review.

The National Bureau of Standards in U.S.A. has for some years been investigating various factors involved in the casting of red brass (85 Cu, 5 Sn, 5 Pb, 5 Zn), and during the last year a further paper has been contributed by Gardner and Saeger.[8] This dealt with the effect of aluminium and antimony ; the former is shown to be deleterious even in amounts of about 0·02%, whereas very much larger quantities of antimony could be tolerated without loss of pressure tightness, strength or ductility. Other papers on cast red brass include one by Parsons,[9] who showed the adverse influence of moisture from damp ladles on the soundness of cast products, and another by Rahm,[10] who made a study of the distribution of structural and physical characteristics throughout castings.

At the International Foundry Congress, held this year in London, general reviews were presented on such subjects as the influence of gases on metals[11] and the properties and production of copper and copper alloy castings for conductivity applications.[12]

Kinzel[13] has also reviewed the subject of copper castings for conductivity applications, with special attention to some of the modern precipitation hardened alloys.

Properties of Copper and Alloys with Tin, Zinc and Silicon

For some years there have been doubts as to whether tough pitch copper becomes " gassed " when it is heated in carbon monoxide. Investigations carried out many years ago indicated that gassing occurred to a somewhat less pronounced extent than in hydrogen, and this finding has been generally accepted. However, later considerations led to some doubts on the matter, and in his recent paper Ransley[14] definitely shows that tough pitch copper is not " gassed " by carbon monoxide ; a reduction of the oxygen content occurs by diffusion to the surface, where it combines with the carbon monoxide, which itself is insoluble in copper and does not diffuse into it.

The addition of small amounts of tellurium or selenium to copper in order to improve its machining properties is a development which until recently has made a little progress on both sides of the Atlantic. In U.S.A. the availability of free machining copper has been announced by at least one firm, while in this country Sallitt[15] has included some data in his review on the machining of copper alloys ; the subject is also considered in a publication of the Copper Development Association.[16]

Mainly by paying careful attention to melting conditions, Lepp some years ago found it possible to fabricate copper tin alloys containing more than the conventional 8 or 10% limit, and bronzes containing up to about 14% tin are now reputed to be in commercial production in France.

Chadwick[7] has made an extensive investigation of the fabrication of bronzes containing up to 30% tin, and reports two ranges of ductile alloys—namely, the cold-working alloys containing tin in amounts up to about 15%, and a further group containing over about 19% tin, which are ductile when hot. It was not suggested, however, that the latter are likely to be of commercial importance. Indeed, it is even doubtful if the mechanical properties of the alloys within the range of 10 to 14% are such as to justify their increased cost, but there is evidence indicating that their corrosion-resisting properties are most interesting ; this is a matter which is dealt with in more detail in the appropriate section of this review.

Unckel[17] has provided much information on the technical

properties of wrought brasses and copper after rolling in various directions, also with different grain sizes. The influence of various impurities on the deep drawing characteristics of brass has also been investigated.[18]

Cook and Duddridge[19] reported on the properties of various extruded and drawn brass rods, with particular reference to variations throughout the section, while in a later paper Cook and Davis[20] dealt with various factors influencing the properties of free-cutting brass rod.

In Great Britain silicon bronzes are still comparatively new, and are therefore not used as extensively as in U.S.A., although increased efforts are now being made to encourage their application. These alloys are being tried for domestic water cylinders, in the manufacture of which their excellent welding properties are an asset, and also for household boilers ; such uses are, of course, in addition to the much more important chemical apparatus for which the alloys were first introduced.

The alpha solubility limits of the copper-silicon series have been re-determined by Andersen[21] and Smith,[22] who have made certain modifications to the previously accepted equilibrium diagram.

The properties of silicon brasses in die-cast forms have been investigated by Seybolt and Gonser,[23] who, from an examination of alloys of a wide compositional range, favour an alloy composed of 5% silicon, 10% zinc, 1% manganese, 1% aluminium, balance copper.

Precipitation Hardening Copper Base Alloys

Precipitation hardening alloys continue to occupy the attention of experimental investigators and are still the subject of a large proportion of current metallurgical patents, although it cannot be claimed that large-scale applications of alloys of this type have as yet been made. Indeed, it is to be recorded that, as a class, these alloys have caused misgivings in some applications, especially those which involve service at slightly elevated temperatures. However, such fears have not altogether been proved, and there is good reason to believe that precipitation hardening alloys, probably modified so as to reduce notch sensitivity, will find increased applications for high temperature service. Gillet,[21] in his review, " Some Things We Do Not Know About Creep," had some outspoken comments to make concerning the effect of constitutional changes on creep performance ; Gillet's remarks were concerned not only with alloys which show definite changes in mechanical properties as the result of temper-hardening, but also those, such as the copper-silicon-manganese alloys, which show a variable alpha range unaccompanied by appreciable change of properties.

A review of age-hardening copper alloys has been made by Crampton,[25] and this summarises in a useful manner all the systems—a total of 160—in which changes are known to occur. Many further papers, some of them dealing with new systems, have appeared, and as a large proportion of both investigations and patents are concerned with electrical rather than mechanical properties, these will, for convenience, be considered in a separate section.

Among purely theoretical papers is a study of the diffusion of nickel and silicon in copper by Mehl and Rhines.[26] Two Japanese investigators[27] appear to have re-examined the mechanical properties of a wide range of

8 H. B. Gardner and C. M. Saeger, J. Res. Nat. Bur. Stand, 1939, 22 (6) 707 and Amer. Found. Assoc. Preprint No. 39-20, 1939.
9 R. W. Parsons, Amer. Found. Assoc. Preprint No. 39-19, 1939.
10 A. M. Rahm, Amer. Inst. Min. Met. Eng. Tech. Pub. 1,117 (Metals Technology, October, 1939).
11 G. L. Bailey, Found. Trade J., 1939, 60, 576 and 1939, 61, 9.
12 H. J. Miller, Found. Trade J., 1939, 61, 117 and 140.
13 A. B. Kinzel, Amer. Found. Assoc. Preprint No. 39-2, 1939.
14 C. E. Ransley, J. Inst. Metals. Preprint, 1939.
15 W. B. Sallitt, J. Inst. Metals. Preprint, 1939.
16 "The Machining of Copper and its Alloys." Copper Development Association Pub. No. 34.
17 H. Unckel, Z. Metallkunde. 1939, 31, 104.

18 W. Loskiewicz, W. Kruszec, and J. Szyszma, Metallwirtschaft. 1939, 18, 119.
19 M. Cook and G. K. Duddridge, J. Inst. Metals. 1939, 64, 311.
20 M. Cook and E. Davis. J. Inst. Metals. Preprint. 1939.
21 A. G. H. Andersen, Amer. Inst. Min. Met. Eng. Tech. Pub. 1,126. (Metals Technology, October, 1939.)
22 C. S. Smith, Amer. Inst. Min. Met. Eng. Tech. Pub. 1,073. (Metals Technology, June, 1939.)
23 A. U. Seybolt and B. W. Gonser, Amer. Inst. Min. Met. Eng. Tech. Pub. 1,123. (Metals Technology, October, 1939.)
24 H. W. Gillet, Amer. Inst. Min. Met. Eng. Tech. Pub. 1,087. (Metals Technology, August, 1939.)
25 D. K. Crampton, Amer. Soc. Metals Preprint No. 38, 1939.
26 R. F. Mehl and F. N. Rhines. Amer. Inst. Min. Met. Eng. Tech. Pub. 1,072. (Metals Technology, August, 1939.)
27 T. Ishikawa and Y. Konishi. Nippon Kingoku Gakkai. 8i 1939, 3, 31. (Abs. Metals and Alloys. 1939, M.A. 348.)
28 F. R. Hensel, E. I. Larsen, and A. S. Doty. Amer. Inst. Min. Met. Eng. Preprint. 1939

alloys in this ternary system, and they confirm that optimum-ageing characteristics are obtained with a Ni : Si ratio of 4 : 1. With regard to the properties of these alloys in the cast state, Hensel, Larsen and Doty[28] report considerable variations, and they claim much benefit from the incorporation of small amounts of zirconium.

Copper-nickel-aluminium alloys have received further study by Alexander,[29] who has, in the third published part of his researches, dealt with the effect of heat-treatment on micro-structure. Alloys consisting of copper-cadmium-zinc-nickel-aluminium are cited in a recent patent.[30]

Some features of the copper-cobalt and copper-iron alloy series have been dealt with by Gordon and Cohen.[31] Fetz[32] has investigated copper-nickel-tin alloys in the range of about 70% nickel.

Precipitation Hardened Alloys for Conductivity Applications

Over the past few years there has been considerable activity in connection with precipitation hardening alloys which possess high electrical conductivity in addition to enhanced mechanical strength and hardness, and during 1938 there has been an extraordinary large crop of patents dealing with alloys which exhibit such features. However, it is to be noted that many of these are not exactly novel, as they are concerned with the addition of one or more elements to old, well-established precipitation hardening systems, or vice versa.

Most original of last year's suggestions are those of Crampton and Burghoff,[33] concerning copper-nickel-phosphorus alloys which, within a stated range of 0·25–3·0% nickel, 0·05–0·6% phosphorus, balance copper, but with nickel and phosphorus in the ratio of 3·5 : 1 to 7 : 1, can be heat-treated to yield conductivities of over 50%. Crampton[34] has since claimed that such alloys are of commercial importance, which points to their being somewhat better than the copper-iron-phosphorus series, which were, some two years ago, also suggested for conductivity applications. In both cases it is to be anticipated that rigid compositional control would be necessary, owing to the marked deleterious effects of the particular elements, when present in solid solution, or electrical conductivity.

The binary copper-zirconium alloys have been shown to be amenable to heat-treatment and patents[35] have been granted in respect of the simple alloys and those containing various other elements, including zinc,[36] metals of the iron group,[37] and cadmium.[38]

In three separate patents, the well-established copper cadmium alloys are rendered amenable to heat-treatment by the inclusion of elements having a variable solubility range ; in all cases the tempered alloys have fairly good electrical conductivity and are claimed to be particularly suitable for resistance welding electrodes and contact blocks. These alloys are copper-cadmium-cobalt-beryllium,[39] and copper-cadmium-nickel-silicon,[40] and copper-cadmium-iron-chromium.[41]

Nickel and silicon have also been added to the copper magnesium alloys, and the resultant quarternary alloys are now patented.[42] Copper-magnesium-chromium alloys have also been the subject of a patent,[43] while a further proposed group of high conductivity high-strength materials is the copper-silver-nickel-beryllium range.[44]

Copper-cobalt-iron alloys[45] containing up to 5% of each of the latter two elements, provide yet a further example of the possibilities to the incorporation of foreign elements (in this case iron) in simple precipitation hardening systems (copper-cobalt). By correct heat-treatment of the ternary alloys of suitable composition conductivity properties are superior to those of the simple alloys.

Most of the above-mentioned patents are concerned with the materials in fabricated conditions, but certain of them can be used in the cast form.

Chromium Additions to Copper Base Alloys

The addition of chromium to a fairly wide range of copper base alloys has been investigated by Alexander,[46] whose observations were particularly concerned with annealing characteristics and solubility limits. Small amounts of chromium—i.e., of the order of 0·03%—were shown to retard the grain growth of copper to a most pronounced extent, while with brasses and other alloys similar effects, although slightly less marked, were obtained. Particular mention might be made of the effect of chromium on the softening characteristics of 7% aluminium bronze, it being shown that an addition of 0·25–0·5% chromium resulted in a considerable change in the form of the hardness-temperature curve.

Nishimura[47] has determined the creep properties of various aluminium bronzes and reported excellent results with an alloy having a composition 8% aluminium, 1–2% iron, 0·3–0·4% chromium, balance copper.

Alloys for Corrosion Services

By almost universal consent 70/30 cupro-nickel has hitherto been regarded as the most suitable alloy for condenser tubes, but it has been suspected that service behaviour is much influenced by the presence of comparatively small amounts of other elements in the alloys. As the result of extended experimental trials, the British Non-Ferrous Metals Research Association[48] have, in a recent publication, recommended that tubes for condenser purposes should contain certain minimum quantities of both iron and manganese.

The dezincification of brass is another instance in which small amounts of certain elements are known to play an important part. Fink[49] has made an investigation of the effect of arsenic in overcoming the dezincification of alpha brass, a matter which has been appreciated industrially in Great Britain since about 1925.

Copper-tin alloys containing greater amounts of tin than the conventional bronzes have been subjected to impingement and other corrosion tests by Chapman and Cuthbertson,[50] who arrived at the general conclusion that bronzes containing 10–14% tin were at least the equal of 70/30 cupro-nickel. Hence it is to be anticipated that the commercial possibilities of this development will be carefully investigated, although it must not be assumed that the relative costs of tubes will be in ratio of raw material costs.

Corrosion problems in connection with aircraft radiators were among the matters considered by Sidery and Willstrop,[51] who state that for certain radiator tubes it has been necessary to use copper-nickel alloys.

Production of Bearings from Metal Powders

Sintered bearings made from mixtures of copper and tin powders and graphite have been in vogue for many years, and the technique is thoroughly well established. Hall[52] has recently published some excellent colour photographs showing the structural changes which occur on sintering ; in particular, the development of the delta copper-tin constituent from the particles of tin powder was demonstrated.

29 W. O. Alexander. J. Inst. Metals. Preprint. 1939.
30 Imperial Chemical Industries and American Brass Co. Brit. Patent 503423.
31 R. B. Gordon and M. Cohen. Amer. Soc. Metals. Preprint. No. 39. 1939.
32 E. Fetz. Amer. Soc. Metals. 1939. 27, 106.
33 D. K. Crampton, H. L. Burghoff, and M. Burghoff. Chase Brass and Copper Co. Inc. U.S. Patent 2155404-7.
34 D. K. Crampton. Metal Progress. 1939. 36, 353.
35 F. R. Hensel and E. I. Larsen. P. R. Mallory and Co. Inc. U.S. Patent 2161486.
36 F. R. Hensel and E. I. Larsen. P. R. Mallory and Co. Inc. U.S. Patent 2161467.
37 Mallory Metallurgical Products, Ltd. Brit. Patent 512142.
38 P. R. Mallory and Co. Inc. Brit. Patent 503753.
39 W. J. Clements and H. W. Barron. British Insulated Cables, Ltd. Brit. Patent 501291.
40 Mallory Metallurgical Products, Ltd. Brit. Patent 512143.
41 N. V. Molybdenum Corp. Brit. Patent 505017.
42 F. R. Hensel and E. I. Larsen. P. R. Mallory and Co. Inc. U.S. Patent 2157934.
43 F. R. Hensel and E. I. Larsen. P. R. Mallory and Co. Inc. U.S. Patent 2164124.
44 F. R. Hensel and E. I. Larsen. P. R. Mallory and Co. Inc. U.S. Patent 2143914.
45 Westinghouse Electric and Manufacturing Co. Brit. Patent 511461.

46 W. O. Alexander. J. Inst. Metals. 1939. 64, 93.
47 N. Nishimura, Suiyokwai-ski (Trans. Min. Met. Alumni Assoc.). 1939. 9–777. (J. Inst. Met. Als. 1939. 6, 132.)
48 British Non-Ferrous Metals Research Assoc. Pub. D 31.
49 F. W. Fink. Electrochem. Soc. Preprint. 75-2. April, 1939.
50 J. Chapman and J. W. Cuthbertson. J. Soc. Chem. Ind. 1939. 58, 100. and 1939. 58, 330.
51 A. J. Sidery and J. W. Willstrop. Metal Industry. 1939. 54, 208.
52 H. E. Hall. Metals and Alloys. 1939. 10, 297.

Somewhat lengthy experience has now been obtained with copper-lead bearings, which are mostly cast by centrifugal and other methods on to steel backings. The important position of such bearings for high-speed internal combustion engines is universally agreed, and much attention has been given to various factors arising in manufacture or service. Many interesting production methods have been proposed, and special mention might be made of those involving the application of powdered metals to the steel backing, sintering at a suitable temperature to form a porous matrix, and afterwards immersion in molten lead or a lead alloy to fill the pores. During the past year several patents,[53] [54] founded on such principles have appeared.

Electro-deposition of Copper

The deposition of copper from cyanide solutions has been undertaken on a much increased scale during the last few years ; the addition of Rochelle salts has permitted a large increase of current density while efficiency has been improved by attention to pH values and other factors. One industrial process[55] announced in U.S.A. just over twelve months ago claims that it gives an efficiency of 100%, and can be operated at high current density. Oplinger[56] has described the various stages by which this process has been developed, although he has carefully refrained from giving information on the particular "addition" which is an essential feature of the process.

The Demand for Aluminium

REFERENCES to the present position of aluminium and its importance in armament production are made in a statement issued by a high executive of a leading firm in the aluminium industry.

"Aluminium is playing a very big part to-day in war material production," says the statement. "All the metal available in this country is now urgently required for war work. Its lightness, ductility and high power-to-weight ratio make aluminium essential for the construction of modern high-speed aircraft. It is used, not only in the manufacture of aeroplane frames, "skins," propellers and other parts, but in the engines, and the demand from the Forces absorbs the entire output.

"Some concern has been expressed by a number of trades at the present lack of aluminium for industrial purposes. The foil and hollowware trades, for example, have complained that many manufacturers may have to close down because of the shortage, and the Public Service Transport Association has represented to the Minister of Transport that the lack of aluminium supplies has raised weight difficulties which necessitate waiving of the present maximum laden weight limits of vehicles.

"The aluminium industry is fully aware of the inconvenience that may be temporarily imposed on industrial manufacturers, but it will be appreciated that service needs must come first.

"There is no doubt that the present demand for aluminium semi-manufactured products such as sheet, tubes, structural sections and stampings, will result in the development of new and stronger alloys. Already, too, the increased production has resulted in reductions of manufacturing costs as the result of standardisation and experience gained with new processes and more up-to-date machinery."

The Welding and Riveting of Aluminium

IN the November issue of this journal reference was made to a book with the above title recently issued by Messrs. Aluminium Union Limited. Our attention has been drawn to another book having the same title, issued by the Northern Aluminium Company, in June, 1938 (second edition), on which the layout and contents has been based.

53 General Motors Corporation. Brit. Patents 496763 and 511726.
54 C. E. Swartz. Cleveland Graphite Bronze Co. U.S. Patent 2161597.
55 E. I. du Pont de Nemours and Co. Inc.
56 F. F. Oplinger. Amer. Electroplaters' Soc. 1939. 181.

Iron and Steel Products
Addition to Import Free List

The Treasury, under the powers conferred upon them by the Import Duties (Emergency Provisions) Act, 1939, have issued the Import Duties (Exemption) (No. 10) Order, 1939, providing for the addition to the Free List, with effect from December 5, 1939, of the following categories of iron and steel products :—

1. Pig iron not already included in the Exemptions Schedule.
2. Ingots.
3. Blooms, billets and slabs.
4. Girders, beams, joists and pillars, whether fabricated or not.
5. Angles, shapes and sections, whether fabricated or not.
6. Colliery arches and pit props.
7. Bars and rods.
8. Plates and sheets.
9. Hoop and strip not already included in the Exemptions Schedule.
10. Railway and tramway rails.
11. Wire (including barbed wire), and wire cable and rope.
12. Upholstery and mattress wire springs.
13. Screws for wood, whether coated or plated or not.

The Board of Trade also announce that the principal iron and steel products, including those exempted from duty by the above Order, and the principal raw materials used in the manufacture of iron and steel, including alloy steel, will, very shortly, be placed on the list of goods requiring Import Licences ; such licences will be issued on the recommendation of the Ministry of Supply (Iron and Steel Control). A detailed announcement on the subject will be issued as soon as the requisite Order has been made.

Ten Years' Progress in Cast Iron

Vitreous Enamelling

The widespread application of vitreous enamel to articles of domestic use is one of the outstanding developments of the last ten years. The application of vitreous enamel to cast iron presents features of considerable technical difficulty, requiring much skill and knowledge for their solution, and the systematic attack on the problems involved has now been provided for in this country.

Foundry Education

Another striking feature of the period has been the interest in foundry education, both for the operative, the technical worker (be he chemist, metallurgist, inspector or tester) and the supervisor or manager. In the latter connection, the British Foundry School, which opened in 1935, has closed for the duration of the war. In supplying a group of highly skilled and highly trained men to the industry, it has performed a valuable service, particularly at the present time.

The war has brought, and will doubtless continue to bring, many new problems, but there is not the slightest doubt that the foundry industry to-day is in a better position to tackle them than at any previous period in its history.

Light Alloys of Aluminium

By Prof. Dr. A. Von Zeerleder, A.I.A.G., Neuhausen, Switzerland

Progress in the development of aluminium alloys is briefly discussed under three main headings : Classification and composition, casting and working operations, and applications. The author compares relative costs in the use of aluminium alloys with certain other metals, and refers to factors to be considered in the selection and use of aluminium alloys. It was the author's intention to read this paper before the recent Dundee meeting of the British Association for the Advancement of Science, but was prevented through the outbreak of war.

ALUMINIUM unites readily with a great number of metals to form useful alloys. One or several elements may be added to aluminium, and, in consequence, a very large number of aluminium alloys have been developed in addition to well-known compositions and proprietary alloys, with the result that the user of aluminium alloys is often in a quandary in selecting the most suitable alloy for his particular purpose from the great number that are available. In " Gmelins Handbook der anorganischen Chemie " I published all the aluminium alloys known to me, indicating their composition and mechanical properties. The tables given in that handbook comprise about 850 different alloys, which were reduced to 250 in my " Technology of Aluminium and Light Alloys." But the layman is often perplexed and justly suspicious over the great multitude of the light alloys, and, with certain exceptions, this high number may be usefully reduced to about two dozen alloys, about half of which are casting alloys and the remainder used for forging, rolling, and extrusion purposes. In addition, there are several special alloys, such, for instance, as those developed for die-castings and for pistons for internal combustion engines. In this brief survey it is proposed to consider aluminium alloys under three main headings :—

(a) The classification and composition of those in general use.

(b) Working of the casting and wrought alloys.

(c) Applications.

Classification and Composition

It is convenient to classify aluminium alloys into two main groups according to their physical properties, which, broadly, can be separated into—

1. The ordinary alloys, which are used without heat-treatment.

2. The heat-treatable alloys, which depend upon some form of heat-treatment for improvement in their physical properties.

The aluminium alloys of high strength generally belong to the second group, but they are more difficult to work than the less strong non-heat-treatable alloys. The alloys in each of these groups are further sub-divided into casting and wrought alloys. Wrought alloys in the first group may be work-hardened during various working operations, but this is distinct from the properties obtained by the heat-treatment of alloys of the second group, the elongation being reduced by cold-working but not by heat-treatment.

Casting Alloys

Referring first to the ordinary casting alloys, we find the copper-aluminium or " American " alloy, so called because it was in America that it was initially developed and used to a large extent, and also the old copper-zinc aluminium base " German alloy." Both these alloys were in common use at the end of last century and are still used in important quantities for ordinary machinery castings, as, for instance, in the automobile industry. In the year 1920 the American, Aladar Pacz, discovered that silicon, which had previously been regarded as an unsuitable alloying constituent, when added to aluminium in suitable proportions, gave a very fine-grained structure after the alloy had been submitted to a refining process with sodium. The structure of a
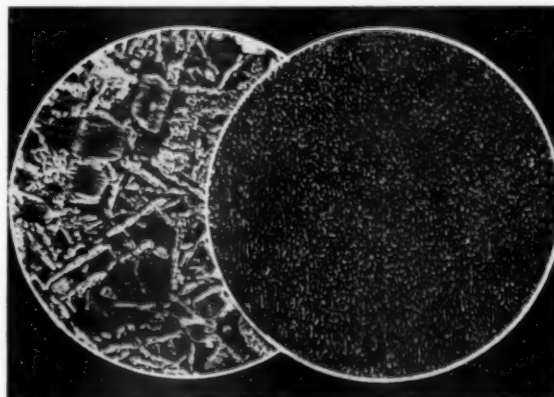
Fig. 1.—Structure of Silumin (Alpax), as cast.
Left—Untreated.　　　　Right—Treated with sodium.

silicon-aluminium alloy, before and after treatment with sodium, is illustrated in Fig. 1. This alloy, known as Alpax, is the chief of the eutectic silicon-aluminium ; one of its outstanding features is its good casting properties, as is shown by the comparative results of fluidity tests shown in Fig. 2 ; it is, therefore, not surprising that its application for castings has grown considerably.

Recently, increasing use has been made of the magnesium-aluminium group of alloys with a magnesium content ranging from 3 to 12%, containing a small percentage of manganese, titanium and/or beryllium. The alloys of this group are remarkable on account of their high strength without heat-treatment, as well as of their resistance to corrosion, especially against sea-water. Birmabright was the first successful alloy of this type, and is claimed to be

Fig. 2.—Fluidity tests showing the influence of silicon content on the length of the test-piece.

1. Pure aluminium. Spiral length, 400 mm.
2. Anticorodal (2% Si). Spiral length, 310 mm.
3. Anticorodal (5% Si). Spiral length, 410 mm.
4. Silumin (Alpax) (13% Si). Spiral length, 730 mm.
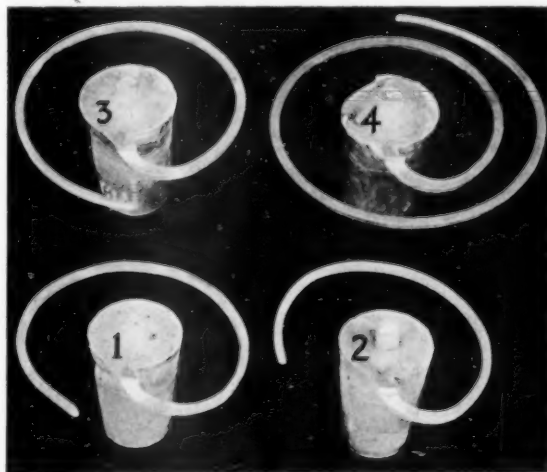
the most widely applied alloy in this range, especially for applications which are required to be resistant to sea-water corrosion. Particularly noteworthy is the influence of the addition of a few hundredths per cent. of beryllium, which eliminates nearly completely the sensibility to oxidation of the magnesium-aluminium alloys when casting in green sand moulds.

With regard to special alloys for gravity and pressure die-casting, mention may be made of the aluminium alloys with copper, nickel and silicon—for example, the alloy of the following composition :—

Magnesium .... 4·0%
Copper .... 2·0%
Nickel .... 2·0%
Aluminium .... Remainder.

On account of the ever-increasing demand for high-strength heat-treatable casting alloys have been developed. For this we are largely indebted to the former Director of the Metallurgy Department of the National Physical Laboratory, the late Dr. W. Rosenhain, for his pioneer researches which resulted in the development of " Y-alloy." He was the first worker to refute the opinion then held that only wrought aluminium alloys could be hardened by heat-treatment. The Y-alloy is a copper-nickel-magnesium aluminium alloy, characterised, apart from its high strength at room temperature, by high strength at elevated temperatures ; a property which has proved of great importance in motor and aeronautical engineering.

Many investigations followed this discovery by Dr. Rosenhain and his collaborators, probably the most important results being the development of the Hiduminium RR series of alloys by Hall and Bradbury and W. C. Devereous. These alloys, which included the casting alloys

Without titanium.   With 1.2% titanium.
Fig. 3.—Influence of the titanium content on the grain size of aluminium of 99.5% purity.

RR 50 and RR 53, have since been subjected to intensive development by High Duty Alloys, Ltd., in collaboration with Rolls-Royce, Ltd. The main constituents of these aluminium casting alloys also comprise copper, nickel and magnesium. In addition, however, the composition includes titanium, taking advantage of the exceptional grain-refining property of this element. As a result of further research, it has been found that, in addition to titanium, other elements, such as cerium, zirconium and niobium, have a similar influence on the grain size. It may be opportune to mention that, generally, the mechanical properties of an alloy are superior the finer its grain structure. Especially is this true in the case of sand castings, where with increasing section the grain tends to become coarser or less strong.

The refining influence on an aluminium casting of high

TABLE I.—MECHANICAL PROPERTIES AND COMPOSITIONS OF ALUMINIUM CASTING ALLOYS.

Group of Alloys	Denomination	Cu	Zn	Si	Mg	Mn		Qual.	σS kg/mm²	B kg/mm²	δ %	H kg/mm²
Cu-Al	American alloy	7–9						S	6–10	12–18	3–0·5	60–90
Cu-Zn-Al	German alloy	2–5	8–12					K	7–11	12–20	3–0·5	70–100
Ni-Cu-Al	Alloy Y	4		1·5			Ni 2	U S	18–22	18–20	1–0·5	80–95
								B		24–27	0·8–0·3	100–115
								U K	20–23	19–21	1–0·5	85–100
								B		26–34	1–0·5	100–120
	RR 50 Hiduminium	1·3		~2	~1		Ni 1·2 Fe 1 Ti 0·1	U S	10–13	15–18	2–5	55–65
								B	15–18	18–20	1–3	70–75
								U K	10–13	18–20	3–7	70–75
								B	17–22	20–25	2–6	75–85
	RR 53 Hiduminium	2·2		1·2	~1·5		Ni 1·3 Fe 1·4 Ti 0·1	U S	12–15	17–19	1–2	70–80
								B	23–28	25–30	0·5	125–140
								U K	12–15	19–21	0·5–1	75–85
								B	26–33	28–36	0·3–0·6	136–150
Si-Al	Silumin (Alpax)			11–13·5				S	8–9	17–22	8–4	50–60
								K	12–13	18–26	5–3	60–80
Cu-Si-Al	Copper-Silumin	0·7–0·9		11–13·5		0·2–0·5			similar as with Si-Al			
Mg-Si-Al	Silumin Gamma			11–13·5	0·1–0·5	0·4–0·6		S B	11–15	25–29	4–1	80–100
								K B	15–22	26–32	1·5–0·7	90–110
Mg-Al	Birmabright				3·5	0·5		S	7–10	12–16	2–4	55
	Peraluman 7			0·1–1·5	4–12	0–1	Sb 0–1	S	9–10	15–20	5–2	60–70
								K	12–14	22–26	10–5	70–80
Si-Mg-Al	Anticorodal			2–5	0·3–2	0·5–1		U	10–13	13–18	3–1	60–70
								S A	15–18	17–25	4–2	70–80
								B	22–29	23–30	1·5–1	85–100
								U	12–16	15–20	5–1·5	60–80
								K A	16–19	20–27	5–2	70–90
								B	24–29	25–30	2–1	90–105

S = Sand castings.   K = chill castings.   U = not heat treated.   A = partly age-hardened.   B = fully age-hardened.
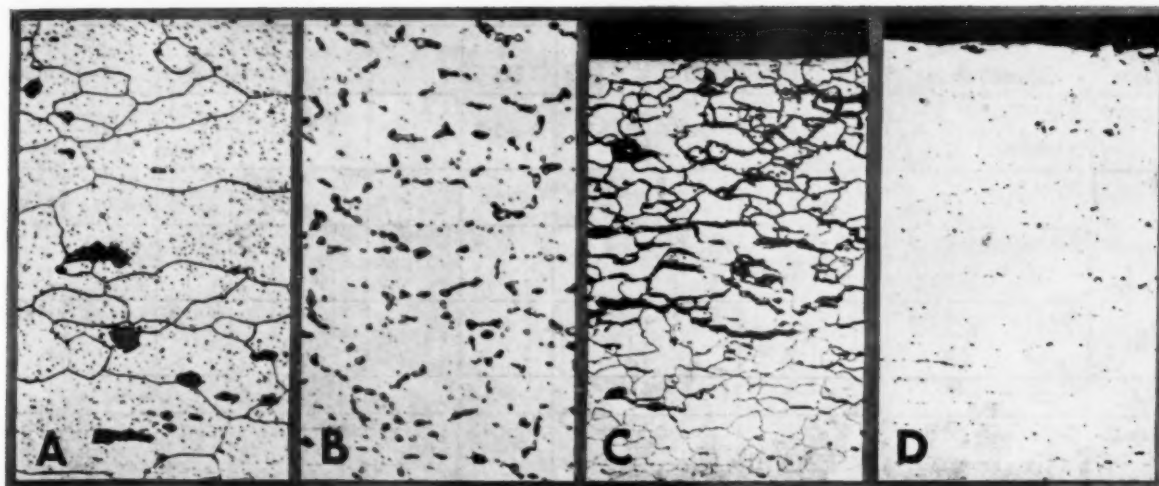
A. The initial alloy—annealed. B. Similar alloy after special heat-treatment. C. As A after attack by 3% NaCl + 1% HCl for 24 hours. D. As B after attack by 3% NaCl + 1% HCl for 24 hours.

Fig. 5.—Intercrystalline corrosion of magnesium- alloys. (Peraluman 7.)

purity by the addition of only 0·1% of titanium is shown in Fig. 3, while in Fig. 4 is shown the influence of grain size on the mechanical properties of several aluminium alloys cast under standard conditions, but of varying sectional area.

Amongst the heat-treatable casting alloys, the magnesium-silicon-aluminium alloys, known principally as " Anticorodal," have become important owing to their good strength combined with good resistance to corrosion. Following the discovery that a small magnesium content confers on the silicon-aluminium alloys the property of becoming hardened by heat-treatment, those alloys, known as "Alpax," have been made heat-treatable, by small additions of magnesium, with the result that the strength of the normal Alpax alloy has been increased from
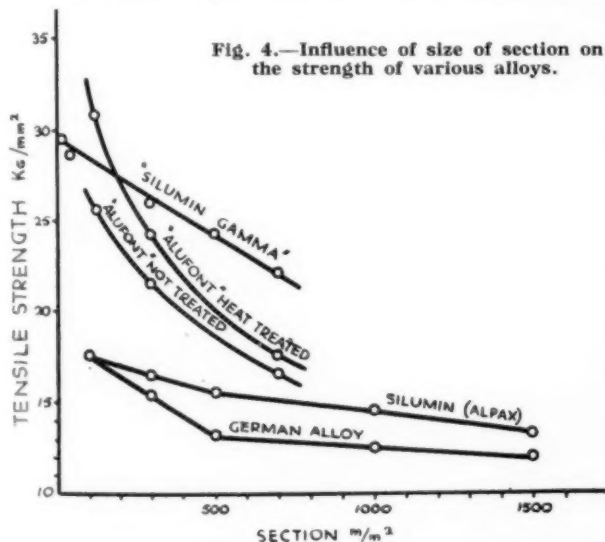

Fig. 4.—Influence of size of section on the strength of various alloys.

15–20 kilogs./mm.² to 25–30 kilogs./mm.² Mention may be made of what can be regarded as the latest heat-treatable aluminium alloy, that of " A P 33 " or " Alufont 3." It contains 4% of copper and relatively small contents of magnesium, manganese and titanium.

The mechanical properties of these various casting alloys and their compositions are given in Table 1.

Wrought Alloys

Of the ordinary wrought alloys, the magnesium-manganese aluminium alloys have gained considerable importance among the non-heat-treatable group of alloys, but it should be remembered that with the super-saturated alloy, containing more than 5% of magnesium, there is a danger of intercrystalline corrosion unless the alloys have been improved by a special heat-treatment. The effect of intercrystalline corrosion will be observed in Fig. 5.

As with the casting alloys, the magnesium-aluminium wrought alloys containing up to 12% of magnesium are a relatively recent development. The use of super-purity aluminium with these alloys give especially good results. Without heat-treatment, these alloys possess high strength together with good resistance to corrosion, but, as in the case of the alloys previously mentioned, there is the danger of intercrystalline corrosion unless they are suitably treated. For many purposes heat-treatable alloys may be essential, but for secondary work, where the components are not so highly stressed, medium-strength alloy sheet in the appropriate temper offers the combination of properties required for forming without the complication and expense of heat-treatment, and, in addition to the alloys already mentioned, the manganese-aluminium and silicon-aluminium wrought alloys fill a useful place for structural purposes. The former in sheet form is about 30 to 40% stronger than pure aluminium in the corresponding temper, and yet is practically as ductile. The silicon-aluminium alloy has rather better mechanical properties in the softer tempers, and is very suitable for welded constructions.

The discovery of the heat-treatable aluminium alloy by Wilm in 1906 was the starting point from which our knowledge of heat-treatable alloys has been developed. The original composition of the alloy Duralumin then produced contained copper, magnesium and manganese, and, although considerable development has since been made, as will be seen in Table II, the composition remains substantially the same. The " Y-alloy " invented by Dr. Rosenhain has also been used as a wrought alloy, but it has now been substituted to a large extent by the R R alloys 56 and 59. The range of R R alloys now available has increased, and it is interesting to note in Fig. 6 the change in structure of the various alloys in this group.

If the highest strength is not necessary, but a reasonably strong alloy with good resistance to corrosion, the magnesium-silicon-aluminium alloy " Anticorodal " can be used advantageously. The Duralumin type of alloys are also becoming highly corrosive resistant as a result of a thin layer of pure aluminium or of magnesium-silicon aluminium alloy as in Fig. 7. Recently, aluminium alloys with the combination $MgZn_2$ as the alloying component are also mentioned, but these alloys are very sensitive to stress corrosion, which has not yet been entirely overcome.

TABLE II.—Composition and Mechanical Properties of Aluminium Wrought Alloys.

Group of Alloys	Denomination	Cu	Zn	Si	Mg	Mn		Qual.	σS kg/mm²	σB kg/mm²	δ %	H kg/mm²
Mg-Cu-Al	Avional Duralumin	3·5–5·5		0·2–1·5	0·2–2	0·1–1·5		W B C	6–14 24–36 38–50	16–22 34–52 42–58	25–15 24–8 15–5	40–60 90–140 120–150
Ni-Cu-Al	Alloy Y	3·8–4·2			1·3–1·6		Ni 1·8–2·2	W B	6–14 22–30	16–22 33–42	25–15 20–8	40–60 100–120
	RR 56 Hiduminium	2		0·7	0·8		Ni 1·3 Fe 1·4 Ti 0·3	B	36–39	43–47	10–20	120–160
	RR 59 Hiduminium	2·3			1·6		Ni 1·3 Fe 1·4 Ti 1·3	B	33–36	41–44	6–10	120–150
Cu-Al	Lautal	4·5–6		0·2–0·5		0·4–0·6			similar as with Mg-Cu-Al			
Si-Mg-Al	Anticorodal			0·3–1·5	0·5–2	0–1·5		W A B C	6–8 16–21 27–32 33–38	11–13 18–28 26–35 35–42	27–15 25–12 20–10 10–2	30–40 50–70 60–100 100–120
Mg-Al	Peraluman 5–7				2·5–12	0–1·5		W H	12–18 30–40	20–45 35–48	25–15 15–10	45–90 60–100
	Birmabright				3·5	0·5		W H	10–13 30–35	22–25 32–38	20–25 2–5	50–60 85–95
Mn-Mg-Al	Peraluman 2				2–2·5	1–2	Sb 0–0·2	W ½H H	10–16 22–27 28–35	16–24 20–33 30–40	25–15 8–4 5–2	50–60 60–80 70–90
Si-Al	Silumin (Alpax)			12–13·5				W ½H H	6–8 12–15 15–20	12–15 15–20 18–25	25–15 10–3 5–2	40–50 50–60 60–80
Mn-Al	Aluman		·			1–2		W ½H H	5–6 14–17 18–22	10–15 14–18 18–25	35–20 15–5 5–2	20–40 40–50 50–60

W = soft. A = partly age-hardened. B = fully age-hardened. C = fully age-hardened and cold worked. H = cold worked.
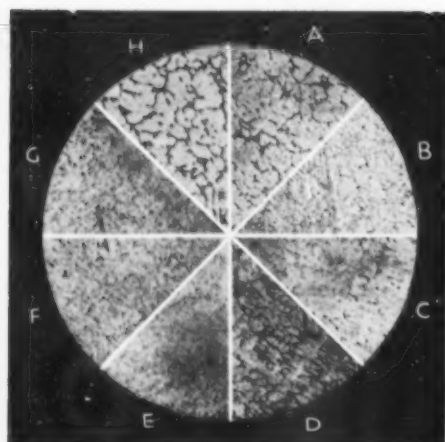
The Working of Aluminium Alloys

The great development in the use of aluminium alloys is due largely to their inherent properties and their ready adaptability to industrial requirements, but an important contributing factor has been the intensive work carried out to develop successful methods for the production of material or components from the alloys. All the main developments in manufacture of aluminium alloys have been followed by careful work to develop a suitable working technique, whether for casting, rolling, forging, extrusion, etc.

Casting Alloys

In addition to sand castings of the most intricate shape, aluminium alloys can be cast in chill moulds either by the gravity process or according to the pressure die-casting methods; an example of the latter process being shown in Fig. 8. The influence of the pouring method on the structures, and therefore on the mechanical properties of the alloys, is shown in Fig. 9, while Table III gives comparative tensile strengths of sand- and die-castings.

The chief advantage of pressure die-castings is the high degree of accuracy of the components produced, which can often be used without further finishing. In consequence of the intricacy of the moulds, pressure die-castings can only be applied economically when the number of any individual component is large and for relatively small parts up to about 10 kilogs. in weight. In view of the higher strength of components which are chill cast, this method should be used in preference to sand casting whenever possible, especially when superior strength is desirable, and when the number required justify the high cost of the metal die.

Wrought Alloys

For many purposes the alloys must be worked, although in the first instance an ingot of suitable size and shape is cast. Whether this ingot or billet is rolled, pressed, extruded or otherwise deformed by the application of severe mechanical stresses, the temperature range for successful working is fairly narrow, particularly for the strong alloys, and generally the power required to carry out these operations is greater than is necessary for ordinary steel, when worked at their respective temperatures. But aluminium alloys, without too high a magnesium content, are very ductile, and permit of a high degree of plastic deformation. In addition to normal working by rolling and forging, aluminium is readily extruded, by suitable presses, to bar, tubes, and a wide variety of sectional shapes, in the same manner as the copper and zinc alloys. A modern press for this purpose is shown in Fig. 10, some of which now operate at pressures of 5,000 tons. Some indication of the range of sections available by this process

Fig. 6.—Micro-structures of a series of " Hiduminium " RR alloys.

(A) RR 50 sand cast (heat-treated).

(B) RR 53 die cast (as cast).

(C) RR 53 die cast (heat-treated).

(D) RR 56 forged bar (annealed).

(E) RR 56 forged bar (fully heat-treated).

(F) RR 59 stamping (annealed).

(G) RR 59 piston (fully heat-treated stamping).

(H) RR 50 sand cast (as cast).

is illustrated in Fig. 11, but the possibilities in section designing are almost unlimited, and the costs for extrusion dies are relatively low. The possibility of the rapid supply of extruded section, although in small quantities, is an important feature, and offers unlimited scope to users.

Another working possibility which offers scope for the use of aluminium is that of impact extrusion, as in Fig. 12. This method

Fig. 7.—" Avional " plated with aluminium of high purity.

has long been applied to soft metals, such as lead and tin. Not only the well-known collapsible tubes for cosmetics, colours, tooth-pastes, etc., but also as shown in Fig. 13, parts of technical apparatus and machines can be produced in large quantities from aluminium in this way. As with pressure die-casting, the impact extrusion process is only suitable when large numbers are required, because of the cost of the tools involved, but when numbers justify this cost, the high degree of accuracy and low manufacturing costs are advantageous.

Applications of Aluminium Alloys

It must be pointed out that aluminium is an expensive metal. On the other hand, however, with magnesium, it has the lowest specific weight of the metals in general use ; this is one of the most important factors which justify its use. When calculating the possibilities of using aluminium alloys, the price per unit of weight should not be considered, but rather the price per unit of volume in comparison with that for other metals that may be suitable ; if possible, it is better to have the price of individual components. One great advantage is the excellent machinability of these alloys.

Another characteristic of the aluminium is its low modulus of elasticity, which at 7,000 amount to only one-third that of steel. Although this characteristic is a disadvantage when the component is required to sustain bending stresses, the low modulus is advantageous because of the higher elastic forming property under tensile and compressive

Fig. 8.—Pressure die-casting machine in operation.

Fig. 10.—Showing a 3,000-ton extrusion press.

stresses. In any case, the modulus of elasticity must be taken into consideration when an appropriate construction is desired. It follows that, in most cases, it is wrong to design a component for production in light metal exactly similar to that which had previously been made in heavy metal. It is often necessary to redesign the component so

TABLE III.

TENSILE STRENGTHS OF SAND AND PERMANENT-MOULD (CHILL) CASTINGS COMPARED.

Alloy.	Average tensile strength lbs. per sq. inch.		Strength of sand-castings as percentage of that of chill-castings
	sand-castings	chill-castings	
3 L 5 alloy	22,000	25,600	86
4 L 11 alloy (No. 12)	20,000	25,000	80
Alpax	25,000	29,200	85
Silumin β .... (not heat-treated)	26,400	34,200	77
Silumin γ .... (heat-treated)	38,400	41,300	93
Y alloy .... (not heat-treated)	25,000	32,800	76
Y alloy .... (heat-treated)	35,600	38,400	93
Hiduminium RR 50	26,700	31,000	86
Hiduminium RR 53	39,300	45,000	87

that consideration can be given to the characteristics of the light metal.

As light metals are preferably used where a low weight is required, the component or part is designed with a view to saving as much weight as possible, thus the relatively high

Fig. 9.—Influence of the casting method on the structure of the casting.

Fig. 11.—A range of extruded sections.

Fig. 13.—Parts of technical apparatus produced by the impact extrusion process.

price of the metal is not the only consideration. An example may demonstrate this fact numerically. Working on a repetition basis, a motor-car factory produced the main engine casting in iron and in aluminium alloy. It appeared that—adopting a suitable technique in each case—the light metal component was cheaper than that made from cast iron, as is noted in Table IV.
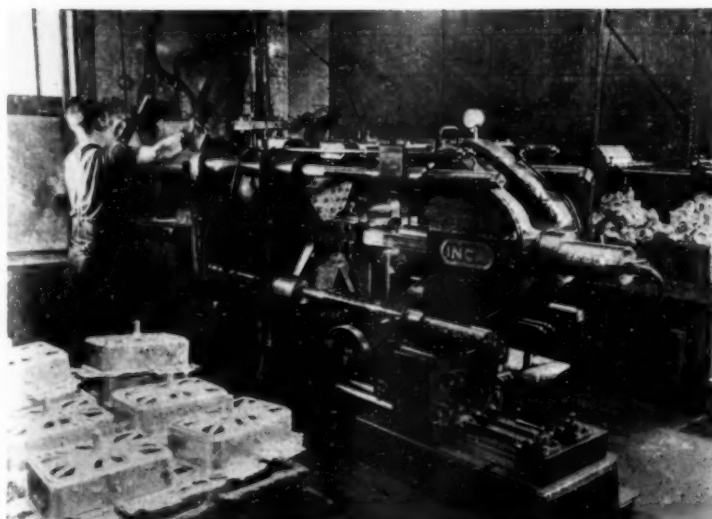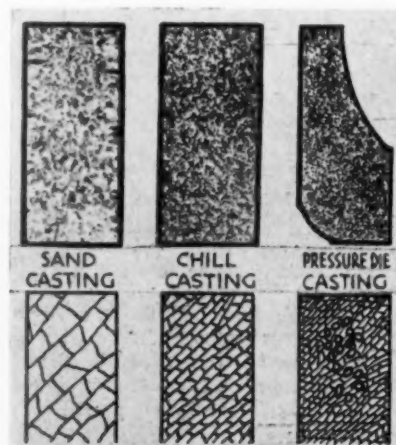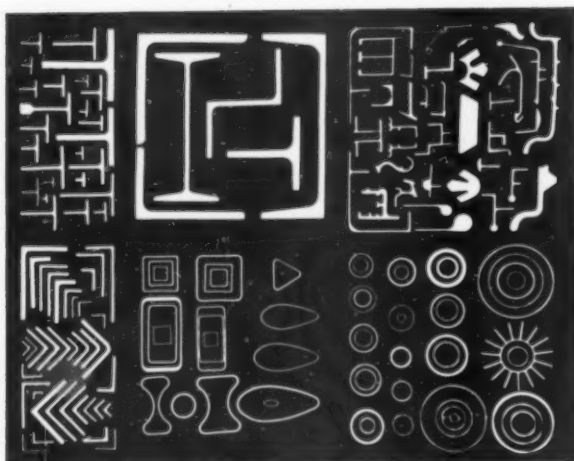
The question often arises : What are the advantages of a low weight of vehicles ? The answer is given diagrammatically in Fig. 14, which gives a comparison in time and speed between two trains, the carriages being constructed mainly of steel and aluminium respectively. The diagram shows that with a low weight the service costs are lowered and the speed of transport can be notably increased ; especially when frequent stops and starts are necessary the saving of weight is important because of the shortening of distance travelled during the restarting. If higher speed is not desired the motive power can be reduced to effect economy.

A casual consideration of the use of aluminium alloys in the construction of heavy motor vehicles would give the impression that their relatively high cost would be uneconomical, but the ratio of high pay load to low unladen tare is a factor of great importance. Apart from this fact, the methods of calculation for taxation purposes gives the vehicle constructed in aluminium a distinct advantage. Experience has shown that the reduction in " dead-weight "

In addition to the direct saving of weight in consequence of the substitution of heavy metals or wood by light metals in vehicles, indirect saving is effected on other parts of the vehicle. For instance, if light metal is principally used in the construction of the chassis, the springs, wheels, etc., can be correspondingly lighter. In some instances the

TABLE IV.
COMPARISON OF FOUNDRY COSTS FOR A HOUSING IN ALUMINIUM ALLOY AND GREY CAST IRON.

| | Alpax | | | Cast iron | |
| | Perm. | sand-casting | | sand-casting | |
	mould casting	machine moulded	hand rammed	machine moulded	hand rammed
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Rough casting..	1 8 9	2 12 8	3 4 0	1 16 9	2 1 8
Total, finished casting ready for use	5 4 0	6 9 6	7 4 0	8 3 4	8 8 0
Finished weight.	17½ lbs.	26¼ lbs.	26¼ lbs.	88 lbs.	88 lbs.

reduction of weight has been as much as 50%. In other forms of transport, development in the application of aluminium to shipbuilding is noteworthy. In this case fuel consumption is governed to a large extent by the draught of the vessel, a reduction in dead-weight, without interfering with the load capacity, effects a direct saving in fuel consumption and increases the field of service on
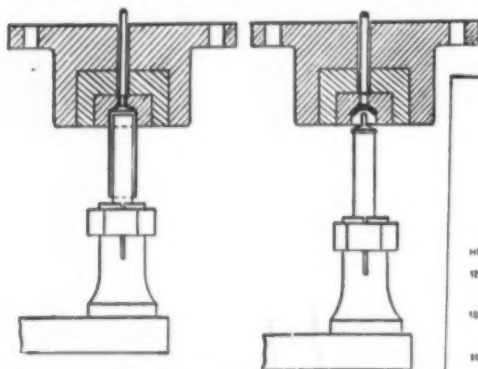

Fig. 12.—Impact extrusion arrangement for making collapsible tubes.

and increased payload, together with other economies resulting, prove aluminium to be an economical material for this purpose, when comparative figures over a reasonable service period are examined.

Fig. 14.—Time-speed diagram giving results of tests on a straight track of light metal and steel trains.
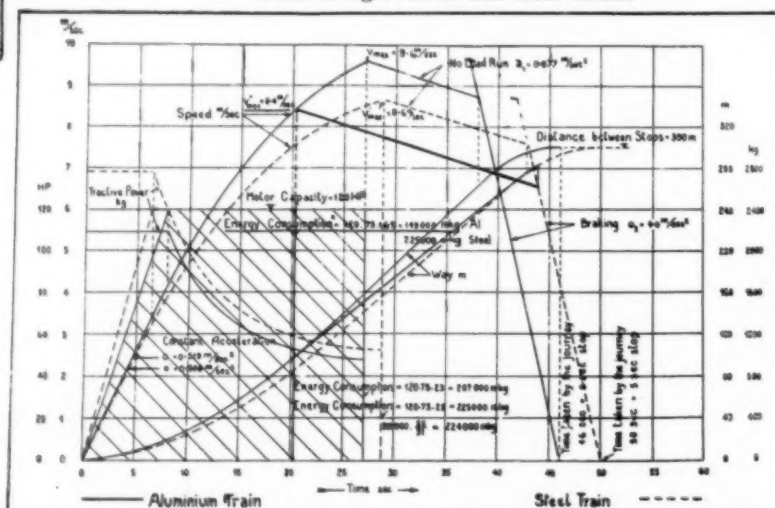
the same bunker fuel. Passenger vessels, in particular, offer considerable scope for the use of light metal because of their superstructure. Apart from this application, however, aluminium and its alloys are being used to an increasing extent in the engine rooms of vessels, for deck fittings, and for ships' lifeboats.

It has only been possible to give a very brief survey of the essential features for consideration in choosing and using aluminium alloys. In the main, the developments made in the production of aluminium alloys in the last decade are the results of pressing demands of industry and the continued collaboration of the metallurgist, engineer and user, will meet exacting demands of the future and open up new fields of usefulness for aluminium.

The Work of the Oxygen Panel

The third lecture in the present programme of the Sheffield Metallurgical Association was delivered by Dr. T. Swinden, at a recent meeting held in Sheffield. The subject chosen was the work of the Oxygen Panel in a sub-committee of the Ingot Committee of the Iron and Steel Institute and the British Iron and Steel Federation, and we are indebted to Mr. L. Rotherham, M.Sc., for his courtesy in sending this brief review of the lecture.

IN a few brief introductory remarks, Dr. Swinden expressed his pleasure in being able to take part in the important series of war-time lectures arranged by the Association. In the early days of the war there was some doubt as to what the position of such societies would be, but it was important that where possible the work should be continued.

He had suggested that a general lecture rather than a more controversial subject would be most suitable, and had chosen the present subject so that interest in the Oxygen Panel might be increased, and so that a discussion might bring useful suggestions to the Committee.

The Oxygen Panel is a sub-committee of the Ingot Committee of the Iron and Steel Institute and the British Iron and Steel Federation. Among the personnel engaged in the co-operative work of the Panel were workers at the N.P.L., Sheffield University and at industrial laboratories ; a suitable combination of academic and industrial workers. The work which has been carried out has been reported in the special reports on the heterogeneity of steel ingots.

In the first place, it is assumed that oxygen is an element which plays an important part in steel-making processes. It is then important that a satisfactory method of determining the oxygen shall be devised. This has been done, and it is now possible by the vacuum fusion method to determine accurately the total oxygen content of a steel sample, and the hydrogen and nitrogen contents are obtained at the same time.

Another method of determining total oxygen is the aluminium reduction method, in which deoxidation is accomplished by an excess of aluminium and the oxygen determined as alumina. The equipment required is cheaper than for vacuum fusion, and potentially the method is of great value.

Having determined the total oxygen content of the metal, it is the next objective to decide how the oxygen is distributed : whether in the form of non-metallic inclusions or as a metallic oxide dissolved in the parent metal. It is obvious that the effect of the oxygen on the properties of the metal will depend on its distribution.

Some information can be obtained from the non-metallic inclusions by microscopic methods, but usually the so-called residue methods are used. In this work the alcoholic iodine, aqueous iodine, and chlorine methods of extraction of non-metallic inclusions have been used, and so far it has not seemed desirable to use electrolytic methods. The residue obtained is ignited and analysed chemically. Many difficulties have been encountered owing to the complicating effects of sulphur, phosphorus and carbide-forming elements, and the methods have required modification to overcome these difficulties. However, with low carbon steels and using many refinements of technique the alcoholic iodine method can give results approximating to the vacuum fusion method.

Another method of estimating the distribution of oxygen in the metal is the fractional vacuum extraction method which is based upon the assumption that different oxides are reduced at different temperatures—e.g., FeO at $1,050°$–$1,070°$ C., MnO about $1,150°$ C., silica at $1,350°$ C, and alumina at $1,650°$ C. Reeve showed that synthetic mixtures of oxides gave these results. Further work on the subject has been justified by results, but while the sum of the fractions agree with the total oxygen determination of the vacuum fusion tests, it is not yet clear that the results are sufficiently reliable to show how the oxygen is distributed among the possible oxides.

It is fortunate that in spite of the present difficult conditions and the pressure of other work, it is possible to carry on the work. Future work is to a large extent indicated by what has been done in the past, but an important aspect of the subject, which is not yet clear, is the oxygen content of molten steel. Since oxygen enters into various reactions during the manufacture of steel, by the open-hearth process, for example, it would be a help in understanding steel-making processes if the oxygen could be determined during melting.

Herty's method attempts to do this by the introduction of aluminium and determining the alumina resulting. This has been used in America, but the work to date of the Panel has not confirmed previous hopes of the method.

In the case of the residue methods, future work will be devoted to the elimination of the modifying effects of various elements.

In conclusion, Dr. Swinden indicated that the results obtained were not always easy to interpret, and require to be considered judiciously. He expressed appreciation for the work of the research chemists, who had carried out the difficult and often laborious work which had been necessary in bringing the methods of analysis to their present standard.

Officers of Institute of Metals for 1940

AT a recent formal general meeting of the Institute of Metals the following nominations were made to fill vacancies occurring on the Council next year : As President, Lieut.-Colonel the Hon. R. M. Preston, D.S.O., managing director of Rio Tinto Co., Ltd. As Vice-Presidents, Dr. S. F. Dorey, chief engineer surveyor for Lloyds Register of Shipping ; Eng. Vice-Admiral Sir George Preece, K.C.B., Engineer-in-Chief of the Fleet ; Mr. A. Y. G. Smout, chairman of metal group companies of Imperial Chemical Industries, Ltd. As Honorary Treasurer, Lieut-General Sir J. Ronald E. Charles, K.C.B., C.M.G., D.S.O., director of British Aluminium Co., Ltd. As Member of Council, Dr. W. E. Alkins, research manager of Thomas Bolton and Sons, Ltd. ; Mr. G. L. Bailey, M.Sc., chief officer, development department, British Non-ferrous Metals Research Association ; Mr. F. C. Braby, M.C., B.Sc., director and London general manager, Frederick Braby and Co., Ltd. ; Colonel P. G. J. Geuterbock, D.S.O., M.C., T.D., M.A., managing director, Capper Pass and Son, Ltd. ; Dr. D. Hanson, Professor of Metallurgy, the University of Birmingham.

Industrial Management and Production Control

Part XII.—Organisation, Extension and Limits of Inspection

By F. L. Meyenberg

Inspection is one of the four main parts of the technical side of a works, and in the organisation it should be regarded on a par with design, planning and production. It is directed mainly to the maintenance of an established quality of the goods manufactured and of the good name of the undertaking. The author discusses some principles of the organisation of inspection, its objects, its staff, and economical considerations.

INSPECTION could be defined " as the art of applying tests by and of measuring appliances, to observe whether a given item of product is within the specified limits of variability," quoting the " Cost and Production Handbook " ; but although some restrictions made in the source have already been omitted in this quotation, this definition seems to be too narrow, in view of what we think should be the object of inspection in industrial works. It may, therefore, be allowed to quote " The New Management,"[*] where we have defined inspection as " the comparison of a condition, a quantity, a dimension, or an effect, etc., as it actually is, with a condition, a quantity, dimension or effect, etc., as it ought to be. It consists, in short, in comparing the actual with the ideal," and this ideal is, as we have explained more in detail, not the real—i.e., never attainable one—but that practical ideal which can be considered as a reasonable compromise of technical, economical and psychological view-points. This practical ideal is often termed " a standard," and it is therefore clear that inspection covers the wide range from comparison, with more or less easily applied fixed standard of measurement as weights, dimensions, temperatures, electrical resistance, tensile strength, hardness, etc.—i.e., from absolute measurement—to that according to feeling or appearance, in using special samples, or even only the instinctive judgment. Further, the close connection is explained between inspection and standardisation expressed in the example of an industrial undertaking as published in Part III of these articles.[†]

Some Principles of the Organisation of Inspection

There inspection is characterised as one of the four main parts of the technical side of the undertaking and put on a par with design, planning and production. As a matter of fact, this independence from production is one of the main demands which is put forward in modern works, and it is undoubtedly in the overwhelming majority of cases a fair and sound principle. For it asks for nothing else than that nobody should be controlled by somebody virtually dependent on him, because control would otherwise too easily become a farce. The longer, however, the problems of organisation are considered, the more it seems that this doctrine is one where no principle is valid without any exception. The economical or the psychological point of view may lead to a deviation from the rule, as, for example, when a second inspection expert, of equal skill as the producer, is not at hand or his services too costly, as in cases of examination of the quality of a surface, where no measuring instrument can be used in practice and the feeling or the opinion of another workman decides the issue. Another interesting example[‡] draws attention to a point where an exaggeration of mechanisation—so often pleaded for by so-called organisers—may have bad consequences. Reference is made to a " system which is claimed to have been adopted in a large engineering works

in Germany, whereby those men who are deemed to possess a sufficient measure of ability and responsibility are permitted to be the sole inspectors of their own work. This honour, which is stated to be highly prized, has so far been awarded to about 500 out of a total of 6,000 employees. In addition, the men thus singled out are expected to draw the attention of the foreman to any errors in drawings or defects in the work which they may discover, to report any mistakes which they themselves may make, and to keep their machines and tools in such a condition as to set a standard to the shop as a whole.

" In certain cases, at present numbering about 50, the delegation of responsibility has been carried even further, and the men are permitted to set their own piece rates and to devise their own methods of performing the work, if they think they can improve upon those formerly employed. It is claimed that under this system the capacity of individuals is developed and the relationship between management and men improved throughout the plant."

It may be repeated that this example should be considered as an exception, but it is certainly an interesting one, which shows how far the pendulum can swing to the other side, opposite to that recommended by Taylor in his functional system of organisation. If we remember cases where the inspection as a comparison with exact measures can be done by untrained men or more especially by girls, and by automatic machines, as in the case of balls for ball bearings, or some parts of munition manufacture, we see that the whole scale of possible methods can be applied, and it is the responsible duty of the expert to select the right one.

It is obvious from these explanations that he can do it only by an intimate knowledge of the technique in question, and it is nearly impossible to develop general principles which should be adopted. Nevertheless, two may be mentioned which, simple as they are, I have often found neglected in practice.

One is that inspection should intervene as early as possible : hence the great importance of the inspection of raw material, whether it is brought from outside or delivered from another part of the works, as is so often the case in metallurgical works. Here may be mentioned as an example the difficulties and costs which arise if the melting shop delivers defective material to the rolling mills, and the results of defects of various kinds, such as pipe, cracks, blow-holes, etc., must be removed from the surface of the rolled material by more or less rough methods, which themselves may be the cause of new trouble. In this connection, attention may be drawn only to the chipping of steel billets with pneumatic hammers and chisels, a job which requires large gangs of men in modern steel works, although all in steel works are only too familiar with the defects of this method. The more the work in the chipping bay is reduced by vigilance and care in casting the ingots, a result assured by a scrupulous inspection during and after the melting process, the better from the point of view of the quality of the finished material. In this sense reductions in the costs of the chipping may be regarded

* " The New Management," page 118.
† See METALLURGIA, December, 1938, page 62.
‡ " Developing Responsibility and Self-Reliance." *Machinery*, vol. 52, No. 1351, 1939, p. 672.

as a measure of the efficiency of the melting shop, if, of course, all other working conditions can be taken as constant.

The second principle of inspection seems to some extent contradictory to the first if it is considered casually: but it is not, as more detailed consideration would show : it is the demand that the work of the inspection should never be driven too far. In any case, it must be known which quality and properties are expected from the finished goods, and the methods of inspection should be adapted to these demands according to the principle, " just good enough." There is a tendency, especially in technical circles, to exaggerate the margin of safety, which, of course, should always be observed ; and this tendency is only too comprehensible if it is kept in mind the great responsibility of, for example, the steel-maker, who has to deliver material for parts of motor-cars or aeroplanes ; but the economical point of view should not be overlooked, and it should especially not be forgotten that technical progress will certainly render obsolete each kind of machine in course of time. If a " too high quality," as caused by exaggerated inspection, has made the machine " too good " and, of course, costly, and if it is therefore still in an excellent state of repair, the possessor will be inclined to use it longer than he should do in view of his capacity of competition.

Objects of Inspection

Again, looking back to the example of the organisation of an industrial undertaking in Part III of these articles, it will be found that the actual inspection has been divided into three parts—that of raw material, of work in progress, and of finished goods ; but we may add to this enumeration that the inspection of all buildings, machinery and equipment used in the work should not be forgotten. This has been mentioned in Part XI on " maintenance," and it is stated that a regular inspection of these parts should be established as a sound basis of maintenance. Here only an additional reference may be made to the inspection of tools and gauges, which is of special importance, as the quality of the production to a large extent depends on the good state and correctness of both ; it is an old truth, " Who does good work, needs good tools." I purposely refrain from dealing in greater detail with this problem, as the superficial survey possible in the scope of these articles would not give the right impression of the extent and difficulties of the organising work involved.

Regarding the inspection of *raw material*, attention may be drawn to the necessity of close co-operation of the receiving depot on the commercial side, and the actual inspection on the technical side of the undertaking. As these two departments rest obviously with two persons of high standing in the hierarchy of the works, but mostly of two completely different spheres of activity, and as the subordinates of both are nearly always persons of different training and mentality, it is often very difficult to bring about this co-operation, and detailed instructions of the division of duties are necessary in order to avoid clashes of competence. Details of the kind of technical inspection of the raw material depend entirely on the special conditions of the works in question, that it is not possible to deal with them on this occasion ; attention may be drawn, however, to the fact that not only should the material be inspected which is used directly for producing goods and is afterwards contained more or less in them, but also all auxiliary materials which are consumed during production, as, for instance, lubricants, cotton waste, pickling acids,, and other chemicals, wood wool, and other packing material also belts, etc. This is sometimes left entirely to the purchasing department and the receiving depot, which are guided only by the price, and it is forgotten that considerable savings are possible by selecting material of a higher original cost but better efficiency. A special case of inspection may be mentioned in which raw materials are taken over, not at the receiving depot of works, but at the works of the supplier, mostly in order to save transport

costs for unsuited material. As this method requires especially trustworthy employees and additional costs, careful consideration is necessary as to whether it is economical.

When inspecting *work in progress* or *finished products* in the metal-working industry, a question arises which is less important in the metal-producing industry, because it is mostly answered by the very nature of the product—that is, whether the material to be inspected should be brought to the inspector, or whether the inspector should follow the flow of the material through the various processes of production ; in other words, whether a centralised or a decentralised inspection should take place ? In metallurgical works the latter method is almost always adopted, because the transport difficulties and costs constitute a hindrance to centralised inspection that is almost insurmountable, in spite of the undeniable advantages connected with it in other respects, especially the possibility of better supervision by the man ultimately responsible. The more refined the products become, however, the nearer the approach to the working conditions in the metal-working industry, and suitable special workplaces for the inspectors must be determined. Here the problem of lighting must be solved, sometimes under great difficulties, especially in old works which are often built without regard to this important requirement, and as the comparatively rough nature of production, with its dust and change of temperature in partly open shops, is opposed to the creation of the conditions necessary for a careful inspection.

Finished products require *packing for transport*, and the inspection should not stop before the best method has been determined. Of course it is not difficult to develop a kind of package to resist even the greatest strain during the transport by land or sea ; but, again, economical reasons demand that it be " just good enough." The inspection must discover methods that are a successful compromise. Although it may be far removed from the interests of readers, an example may be quoted in which tests were carried out in a typewriter factory. A high tower with a flight of winding stairs, formerly part of an old fortress, was used for this purpose. A typewriter, well packed in a wooden box, was allowed to roll the whole length of these stairs, and by gradually decreasing the quality of packing before each test, the limit of packing was found at which the typewriter was still in good workable condition.

Special difficulties may appear when the inspection of finished goods takes place by persons outside the works, as, for example, with orders from Government departments. The circumstances are then reversed from those which are described above when sending employees of the works as inspectors to the supplier of raw materials. It is obvious that every effort will be made to satisfy the demands of the inspector coming from outside and acting as the representative of a customer, and it is necessary to choose persons of high tact to discuss the work with him ; but even their willingness should have limits. I remember quite well a case where this had been overlooked and the compliance to the demands of the outside inspector had been exaggerated. As he was a man thirsty for power, and was not too well versed in technical knowledge and understanding, his demands brought the factory near to ruin before success was achieved in obtaining his recall.

The Staff of the Inspection

It is obvious that the selection and training of the staff of a sphere of work so closely connected with technical and psychological problems as inspection, has to be carried out with special care. It is only natural that efforts have been made to find the right persons for these jobs ; psychotechnical methods especially have been called to help. It should be remembered, however, that a wide range of ability is included in the profession of inspection from an almost mechanical handling of objects to a highly skilled work which can only be done by an expert. These higher stages can best be filled by workmen who have actually done the work they are to inspect, and it is a

good policy to impress on the men in these cases the idea that the change from actual production to inspection must be considered a promotion, as the appreciation of first-class workmanship and of excellent character qualifications. It is obvious that this should also find its expression in the payment of these men.

This leads to the much-discussed question, which kind of wages should be preferred for inspectors. Readers of former articles of this series will not be surprised to learn that I strongly plead for fixed hourly rates ; as a matter of fact, my experience in so many various industries has shown that there are only very rare cases where any incentive in the wage system, as contained in the piece-rate system and in a less intensive form in any bonus system, does not ultimately harm the work of inspection, even if, at first, it seems to be a success. The moral effect of fixed hourly rates on the men, if these rates are sufficiently above the average of those of the ordinary workmen, also should not be overlooked. This last remark applies—I repeat this in order to avoid any misunderstanding—especially to those inspectors who have been promoted to these jobs because of valuable service in actual production.

The Economy of Inspection Itself

As important as inspection is for the quality of the produced goods and for the good name of an industrial undertaking, there is certainly a limit at which inspection ceases to be economical. It is very difficult to give figures when this turning point is reached : it depends on so many variable factors, each influenced differently by the special conditions of the works in question. In this connection only one characteristic may be mentioned—whether the works can retain regular workmen or have to depend on casual labour. The point of view of the management must also change in the course of the development of the production ; a new production calls for more severe inspection, till the training work of the inspection has had sufficient success ; the more this process goes on, the more it will be possible to reduce the extent of inspection. Thus, for example, the inspection of each part of a quantity will proceed to the inspection of samples only, and the number of inspected samples can decrease gradually. The selection of samples, however, should not be done at random, but according to fixed rules, developed from theoretical considerations and practical observations. Whether the right procedure is being followed or not can be recognised only by a special investigation based on suitable statistics, the fundamental figures of which have been given by the inspectors themselves in detailed reports. Here the question arises, how much clerical work should be expected of the inspector. The answer is simple : as little as possible, and in no circumstances more than can be examined afterwards and to draw conclusions. In practice, I have seen too much of these reports which nobody has touched till they disappeared under the boilers, a very expensive and uneconomical " fuel."

The Diffusion of Oxygen in Copper

WHEN copper containing free oxide is maintained at high temperatures, a rapid growth of the cuprous oxide particles occurs, indicating that oxygen is able to diffuse through the solid metal at a very appreciable rate. This fact has been the subject of frequent comment, but no quantitative data seems to have been published. The problem is of considerable theoretical and practical importance, and the recent communication* from the Staff of the Research Laboratories of the General Electric Co., Ltd., is an attempt to fill this gap.

The measurement of the diffusion of oxygen through copper presents a number of experimental difficulties, and in this investigation the methods which had been used in previous research work on the diffusion of gases through metals could not be applied. Previous experiments on the desorption of oxygen from copper suggested that the required diffusion data could be obtained by determining the rates of deoxidation of copper strips under certain conditions. This method was found to be particularly suitable.

The removal of oxygen from copper by heating *in vacuo* was first investigated. As a result of vacuum experiments it was concluded that the evolution of oxygen from copper by this method is controlled by the rate of evaporation from the surface and not by diffusion from inside the metal, further, that the measurement of the diffusion rate is not possible. In the absence of reducing agents, the desorption of oxygen from copper is negligible at temperatures at which copper itself is not appreciably volatile. At more elevated temperatures some loss of oxygen takes place, probably as oxide. Cuprous oxide as a bulk phase, however, is relatively stable up to the highest temperature considered—viz., 950° C.

The above results indicate that the conditions necessary for the determination of oxygen diffusion rate can only be attained in the presence of a reducing agent, which will remove the oxygen from the surface as rapidly as it can arrive there, but which will not penetrate into the copper. Heating in pure carbon monoxide was found to fulfil these requirements. There having been considerable controversy as to whether carbon monoxide diffuses into solid copper or not, initial tests were therefore made to ascertain whether such diffusion is in fact possible, the results of which substantiated the conclusion that carbon monoxide is insoluble in copper.

It is shown that when copper containing oxygen is heated in pure carbon monoxide, the oxygen is removed by a surface reaction. The velocity of this reaction is limited by the rate of diffusion of oxygen to the surface, and is independent of the carbon monoxide pressure over a wide range. The removal of the oxygen from strip copper under these conditions follows the equation $W^2 = kt$, and from measurements on two specimens of copper with different initial oxygen contents the constants of the diffusion process have been derived. The diffusivity constant of oxygen in copper increases from $1 \cdot 1 \times 10^{-9}$ cm^2/sec. at 600° C., to $2 \cdot 1 \times 10^{-6}$ cm.^{2}/sec. at 950° C. ; the associated activation energy is $46 \cdot 0$ K. cal./grm.-atom.

The embrittlement of oxygenated copper in reducing atmospheres is a serious commercial problem, and the author considers that present data appears to justify the following conclusions :—

(a) Compound gases do not diffuse through solid copper—sulphur dioxide, for example, does not diffuse at a measurable rate. Dissociation of molecules absorbed at the surface may, however, be followed by penetration of the constituent atoms.

(b) The embrittlement of copper in reducing atmospheres may in all instances be ascribed to penetration by hydrogen. When embrittlement occurs in gases such as carbon monoxide, hydrogen is present as an impurity, or is produced either by dissociation at the surface or by a side reaction—e.g., $CO + H_2O \rightleftharpoons CO_2 + H_2$.

(c) Reaction between gases in solution with the formation of a new phase cannot occur in the lattice. Reaction can only occur at an interface—i.e., in the present case, at the copper surface, at an oxide inclusion, or possibly at a grain boundary.

The results given in this paper indicate that copper may be completely deoxidised, without impairment of the mechanical properties, by treatment in carbon monoxide free from hydrogen. The process is very slow, however, below temperatures of the order of 800° C. The injurious action of traces of hydrogen, particularly in static atmospheres, has also to be taken into account. This effect follows naturally, since the carbon monoxide removes the oxygen from the surface, and the hydrogen is then free to penetrate into the metal.

* C. E. Ransley. *J. Inst. Metals*, 1939, 65. (Advance copy.)

Aluminium Reflectors
Effect on Heat Reflectivity of Anodic Treatment (Brytal Process)
By A. G. C. Gwyer, B.Sc., Ph.D., and N. D. Pullen, F.I.C.

An investigation on the heat reflectivity of aluminium, anodically treated by the Brytal process, is discussed. The results indicate that even commercial quality metal treated by this method has a reflectivity for heat of nearly 90%, while 99·8% metal is definitely superior to chromium plate. This paper was prepared for presentation at the Second Aluminium Congress at Zürich, which could not be held in September last, as arranged, owing to the outbreak of war.

O F recent years special anodic processes have been developed for the preparation of aluminium reflectors mainly for light, but the treatment should also be suitable for the production of reflectors for long wavelengths. The conditions necessary for the production of a reflecting surface having the desired reflectivity value for white light are now fairly well known. One such process—i.e., the Brytal Process[1]—having been described in detail in a previous publication.[2] Using this process and metal of suitable composition it is a relatively simple matter to produce aluminium reflectors having a total reflectivity for white light of 83–85%. With radiations of longer wavelengths, however, it was found that the results were more erratic, and with the standard methods of treatment and finishing the variation over the infra red region varied by 50% or more.

Fig. 1.—Radiation intensity 1,000°–1,200° K. and water absorption band with maximum at 3μ.

Fig. 2.

Fig. 3. — Infra-red reflectivity of standard super-purity specimen.

Early in 1938 a specimen of Brytal treated super-purity metal treated by the normal process was sent to the National Physical Laboratory at Teddington for measurement of spectral reflectivity over a range 0·23–10μ. Over the visible range the results were up to expectation, but over the infra red and particularly at 3·0μ a marked and unexpected absorption band was discovered.

It was quite evident that such an absorption band would have a marked effect on the total infra red reflectivity if the conditions were such that the maximum intensity of the radiations being reflected occurred at or near this wave-length, and unfortunately such conditions exist in the normal electric fire using elements running at a temperature of approximately 1,200° K. At this temperature the maximum intensity occurs at 2·5–3μ (Fig. 1), shifting towards the shorter wave-lengths with rise of temperature. It was very desirable, therefore, that the cause of the absorption should be investigated and, if possible, removed, since not only does it give rise to lower reflectivity values

measured physically, but the reflector may also be inferior physiologically.

It is unlikely that the temperature at which the domestic heater works was a haphazard selection, and it is significant that the maximum intensity of the radiation emitted by such heaters coincides with a very marked water absorption band—i.e., at 3·0μ,—and it is not unlikely that the sensation of heat is due, in part, to infra red radiations of this wave-length being absorbed preferentially by the body.

Applying this argument to the anodised reflector itself, the question immediately arose as to whether the absorption shown by material treated in the normal manner was not due to the presence of water in the film. It is known that such water does exist particularly in films which have been sealed by treatment in boiling distilled water. On the other hand, there was th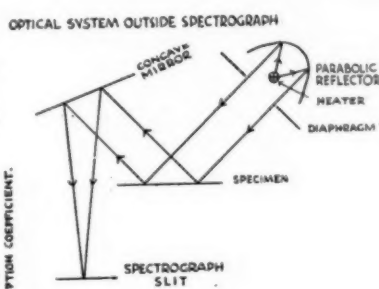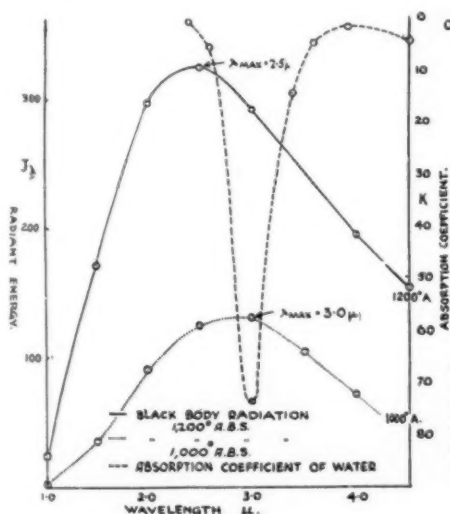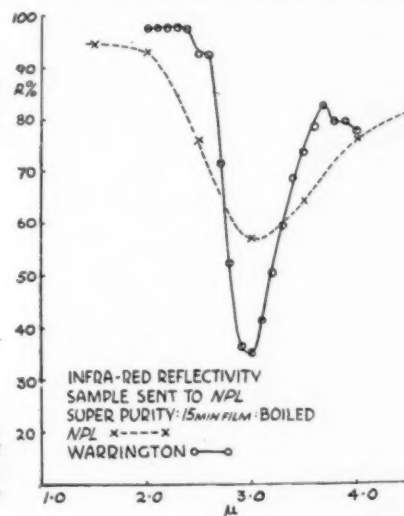e possibility that the oxide film itself or even the wax used for sealing had an absorption band at or near this wave-length, in which case its removal would probably be impossible. It was decided, therefore, to carry out an investigation to find, first the cause of the absorption, and then possible means for reducing or eliminating the effect.

For this purpose a Hilger infra-red spectrometer fitted with a fluorite prism was used in conjunction with a Broca galvanometer. It was necessary to construct an additional piece of apparatus holding the heating element and specimen, and the final arrangement of this apparatus, together with the spectrometer, is shown diagrammatically in Fig. 2.

After calibration, a check test was carried out on the specimen which had been originally submitted to the N.P.L., together with fresh specimens produced for the purpose, and these results are shown in Fig. 3. The total reflectivities were calculated, using a piece of highly polished copper as standard, the absolute reflectivity of the copper being taken as 95–98%, according to the values given in the International Critical Tables for particular wave-lengths.

1 British Patent 449162.
2 Jour. Inst. Metals. LIX (2) 1936, pp. 151-158.

Having confirmed that a definite absorption band did exist, the first part of the investigation was put in hand—i.e., whether this effect was due to an absorption characteristic of the aluminium oxide of the film. Assuming this to be the case, then if film thickness is plotted against reflectivity at $3 \cdot 0\mu$ the log relationship should be approximately linear, the formula being $\log r = -kt$, where r = reflectivity, t = thickness in mm., and k = a constant. Preliminary experiments showed that such absorption as did occur was due to the bisulphate film, since metal treated in the alkaline brightening bath alone showed only a very shallow band. Measurements made on specimens having bisulphate films of various thicknesses also showed that the wave-length of maximum absorption remained constant (Fig. 4), and the reflectivities at $3 \cdot 0\mu$, when plotted logarithmically against film thickness, gave a very approximate straight-line relationship, indicating that the lowering of reflectivity at this wave-length is due to a true absorption and not to other effects, such as interference between the radiation reflected from the metal itself and that from the outer surface of the film.
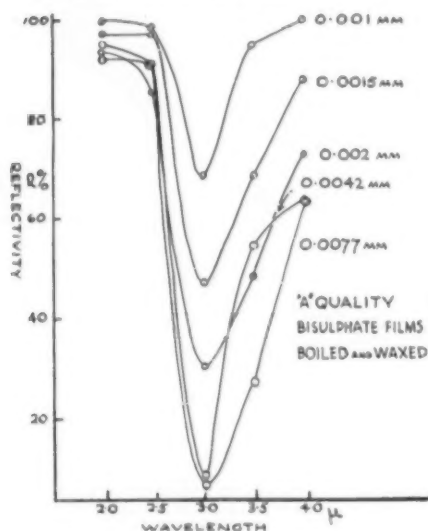
TABLE I.   REFLECTIVITIES AT $3 \cdot 0\mu$.

Treatment.	Bisulphate Film.		
	5 mins. 0·001 mm.	7½ mins. 0·0015 mm.	10 mins. 0·002 mm.
	%	%	%
A. Plain (no after-treatment)	64	57	63
B. Boiled	45	20	28
C. Boiled and waxed	73	55	36
D. Autoclaved	31	18	21
E. Autoclaved and waxed	36	15	24
F. Dyed	61	41	52
G. Boiled same time as F	35	17	29

deleterious effect on the reflectivity ; in fact, it seems to enhance it in this case, possibly by sealing the pores of the film against moisture. On the other hand, all the films that have come into contact with water in any way show lower reflectivities than the unboiled film A, thus confirming our original assumption that the effect is due to water in the film and suggesting a method of improvement.
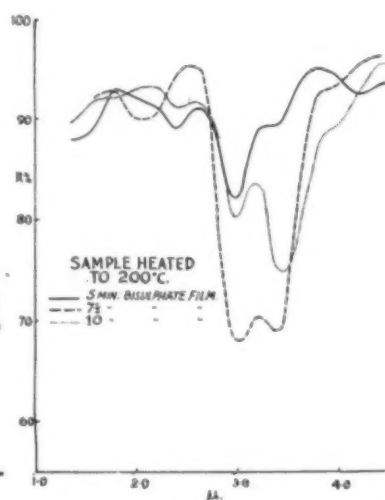

Fig. 4.—Effect of film thickness on absorption at 3_μ.

Fig. 5.—Absorption bands of films heated in air oven for 30 mins. at 200°C.

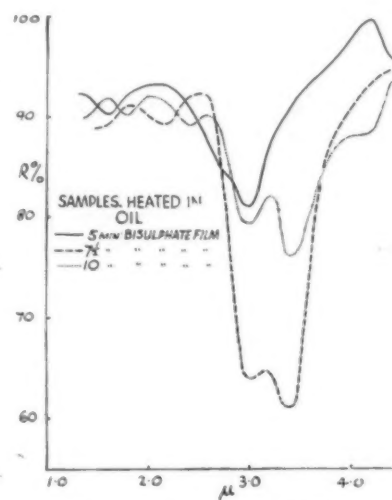

Fig. 6.—Absorption bands of films heated in oil for 30 mins. at 175° C.

The results obtained for the reflectivity of the thicker films were rather more irregular than would be expected under the circumstances, and it seems likely that this can best be explained by the assumption that part, at least, of the absorption is due to the somewhat variable amounts of water and/or wax taken up by the film in the after-treatments of boiling or waxing. The strong absorption of water in the $3 \cdot 0\mu$ region, and the fact that the boiling treatment is known to increase the hydration of the film to a more or less variable extent, both seem to indicate that water is chiefly responsible.

For the purpose of deciding the real cause of the absorption, the following series of $99 \cdot 8\%$ purity specimens were prepared with 5-, 7½-, and 10- min. bisulphate films, with film thicknesses of 0·001 mm., 0·0015 mm., and 0·002 mm. respectively. One set of specimens (A) were left unboiled in order to see if any improvement would result. The reflectivities of the whole series were measured at $2 \cdot 0$, $2 \cdot 5$, $3 \cdot 0$, $3 \cdot 5$, and $4 \cdot 0\mu$ in case bands might be produced at other wave-lengths by the different treatments. As these were not observed, the reflectivities at $3 \cdot 0\mu$ are shown in Table 1.

In general, this table shows an increase in absorption with thickness, although the results for the 7½-min. films are anomalous, probably owing to the effects of interference. Specimen C, the normal Brytal film similar to that tested by the N.P.L., shows a strong absorption. By comparison with B, it can be seen that waxing has no

The dyed specimens gave rather interesting results. They were prepared by immersion for 5 mins. in a boiling solution of a red/orange dye followed by a hot-water treatment for a further 5 mins. before drying and waxing. In these cases the absorption was much less than in the case of specimens boiled for the same total length of time. This rather astonishing fact may perhaps be explained by the assumption that less water is present in the dyed films, the dyestuff taking its place.

In view of these very encouraging results, an attempt was made to improve the reflection properties still further by removal of any additional water that might be present in the unboiled film by means of heat. Two series of films were prepared, one set being heated in an oven at 200° C. for 30 mins., and waxed immediately while still hot, and the other heated in mineral oil at 175° C. for 30 mins. ; in this latter case the film required no waxing. The results for the reflectivities at $3 \cdot 0\mu$ are set out in Table 2.

TABLE II.—REFLECTIVITIES AT $3 \cdot 0\mu$.

Treatment.	Bisulphate Film.		
	5 mins.	7½ mins.	10 mins.
H. Unboiled, heated to 200° C. for 30 mins. and waxed ..	82	68	80
J. Unboiled, heated in oil at 175° C. for 30 mins.	83	64	68

As can be seen, there is a marked improvement over the results for the unboiled films. In fact, it seems that the solution of the problem has been found, since the reflectivities are of a very high order.

Owing to the excellent results obtained with these two treatments, the reflectivity/wave-length curves for these specimens were obtained and plotted in greater detail (Figs. 5 and 6). It can be readily seen from these curves, which confirm the previous high results at $3 \cdot 0\mu$, that the anomaly of the $7\frac{1}{2}$-min. film is due to a spurious band at $3 \cdot 4\mu$, presumably the result of interference, swamping the true absorption. The small humps and hollows seen in these and many other later curves are most probably ascribable to the same cause.

These interference effects make it almost impossible to make a true comparison between films of different thickness, but in spite of this, interesting deductions may be made from the reflectivity/wave-length curves for films of the same thickness with different after-treatments. The results

10 v. and 30° C. in the bisulphate bath. A treatment of 15 mins. in this bath gives a slightly thicker film, with rather greater absorption. The film is then rinsed in cold or warm water to remove adhering electrolyte. Heating is carried out in the air oven at 160°–170° C. for 30 mins., and the films are then waxed as quickly as possible while still hot, the excess wax being removed, when cool, with sawdust. Films prepared in this way contain the minimum of absorbed water, and the treated metal has a reflectivity of about 80% at $3 \cdot 0\mu$—a considerable improvement over boiled films.

TABLE 4.　REFLECTIVITIES AT $3 \cdot 0\mu$.

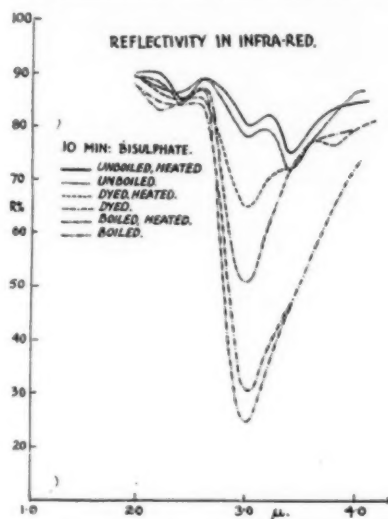| Treatment.	Boiled, Waxed.		Heated, Waxed.
Chromic acid, 15 mins.	14	..	77
„　　　30 mins.	10	..	45
Sulphuric acid, 10 mins.	33	..	79
„　　　15 mins.	22	..	73
Oxalic acid, 15 mins.	19	..	74
„　　　30 mins.	ca. 1	..	65

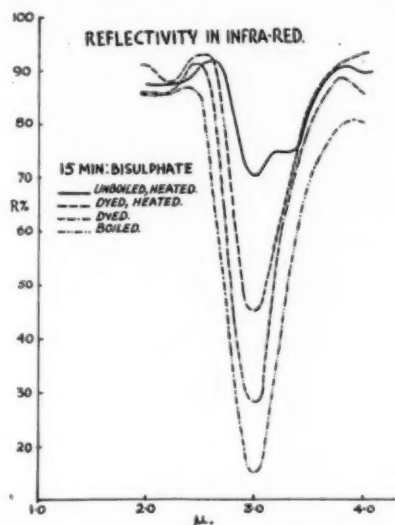Fig. 7.—Infra-red reflectivity of 10-min. films on 99·8% purity metal.

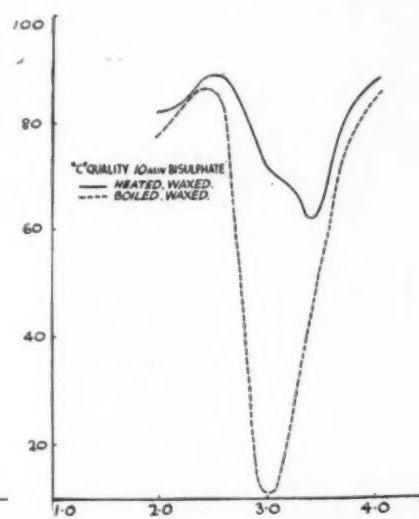Fig. 8.—15-min. bisulphate films on 99·8% purity metal.

Fig. 9.—10-min. bisulphate films on commercial purity metal.

for a 10-min. bisulphate film on 99·8% metal may be seen in Fig. 7. The effects of the heat-treatment of the unboiled films are confirmed by these curves, and films so treated, as well as showing an improvement on plain unboiled and waxed films, are notably superior to any of the other treatments, especially the boiled and waxed specimens. Heating boiled and dyed films also gives slightly improved reflectivity figures, but in no case do the results compare with those for the unboiled heated films. It is probable that the heat-treatment is only capable of removing a relatively small amount of water from the film and that for best results the film must not be allowed to remain in contact with water for too long a time before heating and waxing. A rinse in cold water is generally all that is required to remove any adherent electrolyte. The exact temperature and time of heating specimens were not found to be critical between the limits 150°–200° C. and 15–30 mins. and 30 mins. in an air-oven at 160°–170° C. were generally found to be ample.

Further tests confirmed these observation for 15-min. films (0·003 mm.) on 99·8% (Fig. 8), 10-min. films (0·002 mm.) on commercial quality (Fig. 9), and for 10- and 15-min. films on super-purity metal (Figs. 10 and 11). The minimum reflectivities for a number of specimens at $3 \cdot 0\mu$ are set out in the Table 3.

As a result of these tests, the following method† was adopted for the preparation of heat reflectors :—99·8% metal is lightly polished and given a normal treatment in the alkaline brightening bath, followed by 10 mins. at

† British Patent applications.

TABLE III.—HEAT REFLECTIVITIES AT $3 \cdot 0\mu$.

Metal.	Bisulphate Film, Mins.	Treatment.	R, %
S.P.	10	Heated, waxed	85*
S.P.	10	Boiled, waxed	38
S.P.	15	Heated, waxed	75*
S.P.	15	Boiled, waxed	35
99·8%	10	Heated, waxed	80*
„	10	Not boiled, waxed	78
„	10	Dyed, heated, waxed	65
„	10	Dyed, waxed	51
„	10	Boiled, heated, waxed........	32
„	10	Boiled, waxed	25
„	15	Heated, waxed	70*
„	15	Dyed, heated, waxed	45
„	15	Dyed, waxed	28
„	15	Boiled, waxed	15
Commercial	10	Heated, waxed	70*
„	10	Boiled, waxed	11

* In every case the heated specimens marked with an asterisk show a marked improvement over the others, the results for super-purity being particularly good.

In order to confirm these results for other anodic films, two series of specimens were prepared of the various other anodic processes on 99·8% metal, one being heated and the other boiled and waxed. The results are set out in Table 4.

These confirm the results for the Brytal treatment.

In order to complete this part of the investigation, spectral reflectivity curves were obtained in the same manner for stainless steel, chromium plate, plain aluminium, and lacquered silver. The curves obtained are shown in

Fig. 12. The well-marked minimum in the curve for lacquered silver between $3 \cdot 0$ and $3 \cdot 5\mu$ is probably due to absorption of radiation in the film of lacquer.

As the prime interest in this series of experiments was the improvement of the overall spectral reflectivity of the material for heat radiation from an electric fire element working at $900°$ C., it was decided, at this stage, to devise some means of measuring this property.

For this purpose the same apparatus was used as in the previous experiment, with the spectrometer replaced by a single large thermopile. The source of radiation was made somewhat larger (i.e., about $2 \cdot 5$ cm. long), in order to give measurable readings. It was arranged to operate at a temperature of $900°$ C., having a maximum emissivity at about $2 \cdot 5\mu$. The thermopile, which was placed at the focus

TABLE V.—REFLECTIVITIES FOR TOTAL RADIATION FROM AN ELEMENT AT 900° C.

| Metal Surface.	Reflectivity. %
Polished copper (Standard)	100
S.P. 10 mins. bisulphate, unboiled, heated, waxed ...	98–99
99·8% 10 mins., bisulphate, unboiled, heated, waxed	93–94
Commercial 10 mins., bisulphate, unboiled, heated, waxed	88–89
Chromium plate	89–90
S.P. 10 mins., bisulphate, boiled, waxed	91–92
99·8% 10 mins., bisulphate, boiled, waxed	85
Commercial 10 mins., bisulphate, boiled, waxed ...	79–80
S.P. 15 mins., bisulphate, unboiled, heated, waxed ..	94
S.P. 15 mins., bisulphate, boiled, waxed	86
Stainless steel	89–90
Plain aluminium, freshly cleaned and polished......	98–99
Lacquered silver	96–97
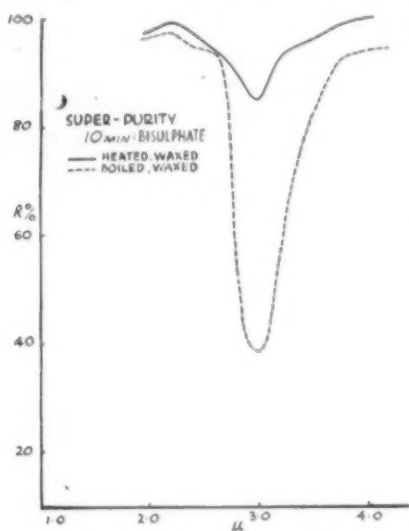
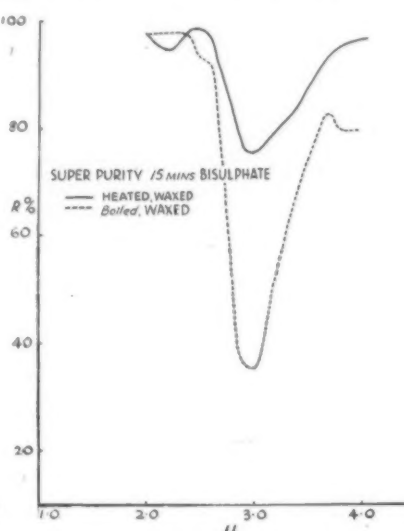Fig. 10.—10-min. bisulphate film on super-purity metal.

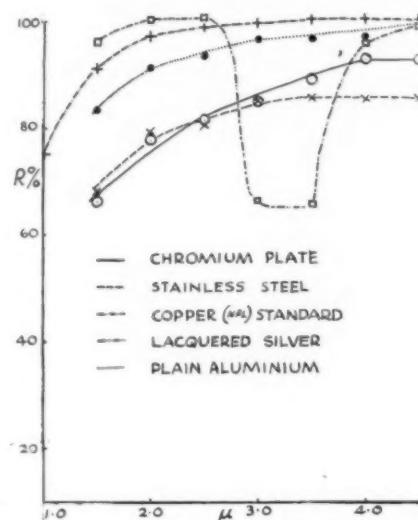Fig. 11.—15-min. bisulphate films on super-purity metal.

Fig. 12.—Spectral curves for plain aluminium and other metals.

of the concave mirror, consisted of a thin copper disc, about $2 \cdot 0$ cm. in diameter, to which the leads of an iron/constantan couple were soldered. The side of the disc towards the incident radiation was blackened and the whole apparatus was enclosed in a wide glass tube to screen it from draughts. The couple was connected to a sensitive galvanometer. After switching on the heater and inserting the specimen in the holder about 15 mins. were allowed for the apparatus to reach equilibrium and then a reading of the galvo. was taken. This reading should be a measure of the total reflected energy. The reading was repeated for the standard copper specimen, and hence the reflecting power of the specimen under test could be calculated, taking copper to have a reflectivity of 100%, a figure which is probably not far from the truth. However, this arrangement was not entirely satisfactory at first, owing to the fact that the galvo. reading drifted slowly but steadily upwards during a series of tests. This was finally traced to the heating up of the glass envelope surrounding the thermopile by the incident radiation. When this was replaced by a filter funnel screened from the radiation by means of an aluminium diaphragm, the drift almost entirely disappeared. The results were the mean of several experiments, and were subject to a certain amount of variation which was difficult to remove, but on the whole they give a fair measure of the reflectivity of the various surfaces to heat radiation from an electric element at $900°$ C. (See Table 5).

These results show that $99 \cdot 8\%$ metal with a 10-min. bisulphate film after heating is definitely superior to chromium plate, in spite of the latter's high reflectivity of 90%, and the results for super purity with a similar treatment are very good indeed. In fact, it does not seem very likely that the results for this material can be much

improved by any further modification of the process. Even commercial quality metal treated by the new method has a reflectivity for heat of nearly 90%.

The authors wish to express their thanks to the British Aluminium Co., Ltd., for permission to publish this work, and also to their colleague, Mr. B. A. Scott, B.Sc., A.R.C.S., for his valuable assistance.

Mr. J. E. Fletcher

WE regret to announce the death at Dudley, in his seventy-second year, of Mr. J. E. Fletcher. Born at Chesterfield and educated in Sheffield, Mr. Fletcher served his apprenticeship in the works of the Clay Cross Company, and became foundry manager and later works manager in the steel works of Thos. Firth and Sons and Cammell, Laird and Co. In 1905 he was appointed chief engineer to N. Hingley and Sons, Netherton, and later became their consulting metallurgical engineer. He was an original member of the Council of the British Cast Iron Research Association, and later became consultant to the Association, particularly on melting practice. He carried out the experimental work and evolved the design of the type of cupola furnace which he patented jointly with the British Cast Iron Research Association, and which became known as the balanced blast cupola, over two hundred installations of which have been made in this country and abroad. He was a Past President of the Staffordshire Iron and Steel Institute, and a member of the Institution of Mechanical Engineers, of which body he was awarded the Bernard T. Hall prize in 1926. He was responsible for many technical contributions to various institutions, including the Iron and Steel Institute. He travelled extensively on the Continent and in the U.S.A. in connection with his business and scientific activities.

Business Notes and News

Motor Generator Sets for a large Steel Works.

In connection with an important contract for electrical equipment now being undertaken by the General Electric Co., Ltd., for the new slabbing mill of John Summers and Sons, Ltd., two interesting motor generator sets have been on test at Witton Engineering Works. The equipment includes six machines—a 700 h.p. 6,600-volt 1,000 r.p.m. synchronous motor is direct coupled to three 135 k.w. 250-volt D.C. generators, and also to two exciters. The smaller of the exciters of the set supplies the synchronous motor, while the larger exciter supplies the three D.C. generators of the set, the three corresponding generators of the second set, and certain other machines. The second motor generator set is identical with the first, except that it includes only one exciter—that for the synchronous motor.

Rhokana Cobalt.

The information given at the recent annual general meeting of the Rhokana Corporation, that the company had sold 2,250,000 lb. of cobalt in the past financial year, is of considerable interest. Only about five years ago Rhokana began to produce cobalt as a by-product from its North Rhodesian copper ore. Since then progress has been so rapid that, except for its neighbour, the Union Minière du Haut Katanga, in the Belgian Congo, the company is the largest producer of cobalt in the world. In these five years the world's output of cobalt has been trebled, and yet the demand has been such that the output has been readily sold at rising prices.

Considerable development in the use of cobalt has been effected in the last 30 years ; in 1907, for instance, the chief use was in the form or oxide in the ceramic industries, and although the requirements of these industries has increased, the increase has not been nearly so important as the growth in the use of cobalt metal. Owing to the remarkable and varied properties which the metal cobalt imparts to other metals, its use has been extended to many industries. It is used in stellite, and in many tungsten carbide cutting materials ; as a component of a number of heat-resisting steels and of corrosive-resisting alloys to withstand chemical, abrasive, and erosive attack. Cobalt is used as a constituent in magnet steels, in electrical resistance alloys for high temperature furnace conditions up to 1,350° C., for the hardening of copper, and in recent years the commercial development of cobalt-nickel electro-deposition has been marked. Apart from Northern Rhodesia, cobalt is mined in other parts of the Empire, such as Canada and Burma.

Scrap Iron and Steel.

Scrap iron and steel are essential raw materials, and every manufacturer and industrial undertaking is being approached by the Iron and Steel Control to effect systematic clearance of all useful material. It should be remembered that over half the weight of metal charged into British steel furnaces consists of scrap. In 1937, for instance, about 7,500,000 tons of scrap were used in the production of nearly 13,000,000 tons of steel ingots. The great bulk came from home sources ; the steel industry, for instance, supplied over 3,000,000 tons from its own melting shops, rolling mills, and structural departments.

So important is scrap that, according to the New York *Herald-Tribune* Britain has completed negotiations for the purchase in America of more than 750,000 tons of scrap iron for shipment within the next three months. This is claimed to be the largest single transaction of its kind in history, involving more than £3,750,000.

Scrap claims a high rank in British trade, and the scrap metal industry has grown into an important organisation, working in co-operation with iron, steel and metal manufacturers. Now that the country is at war, the maintenance in the supply of this type of raw material is increasingly important, and the British iron and steel industry is making every effort to consolidate and safeguard its resources by asking for scrap iron and steel from every works, warehouse and yard in the country. Every manufacturer and industrial undertaking should make a point of liberating all supplies of scrap metal which they are unable to use.

Presentation to Mr. A. J. Grant.

To commemorate his successful year of office as Master of the Cutlers' Company of Hallamshire, the directors and staff of Messrs. Thos. Firth and John Brown, Ltd., have presented Mr. A. J. Grant, the managing director of the company, with his portrait in oils. The portrait ,painted by Captain Oswald Birley, of London, has been greatly admired by all those who have had the opportunity of seeing it.
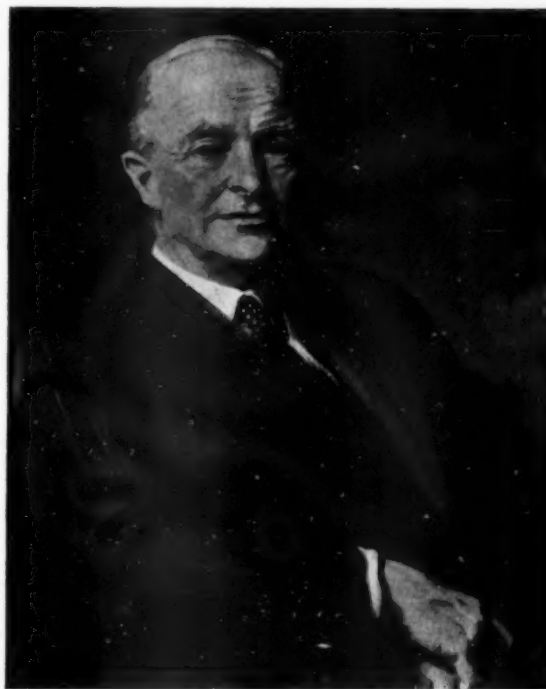
Mr. A. J. Grant, Managing Director of Messrs. Thos. Firth & John Brown, Ltd.

Under ordinary circumstances, the presentation would have been made at a meeting of the subscribers by Mr. John Smith, chairman of the Staff Society, but owing to the outbreak of war, this ceremony could not be held, and the portrait was given to Mr. Grant with the congratulations and good wishes of his co-directors, the members of the Staff Society, and the agents and representatives of the company from all parts of the world. Deprived of the opportunity of voicing his deep appreciation of the gift, Mr. Grant has sent a personal letter to each of the subscribers.

After having been displayed in the main offices at Atlas Works, the portrait now occupies a place of honour at Dore Moor House, and a copy is intended for the Board Room at Atlas Works.

New By-product Cooking Installation.

The South African Iron and Steel Industrial Corporation, Ltd., have placed with a British engineering firm—the Woodall-Duckham Vertical Retort and Oven Construction Co. (1920), Ltd.—an order for a second complete by-product coking installation to be built at their Iscor Steelworks near Pretoria, valued at about £475,000. This new oven battery will comprise 45 top-charged, W-D Becker coke ovens designed for blast-furnace gas underfiring. The ovens will be 40 ft. 8 in. long, 13 ft. high, and 16 in. average width, and the battery will be capable of carbonising 960 tons of washed coal a day. The new battery will be laid out on a new site, but on the by-product side advantage will be taken of the original facilities for extension.

The contract provides for two sets of electro-detarrers for the extended plant, and for a new concentrated ammonia plant capable of manufacturing liquor of 25% strength. The capacity of the benzole plant will be doubled, provision being made, at the same time, for the production of pure toluole. Finally, a pipe-still type of tar distillation plant has been adopted to deal with 100 tons of crude tar per day, and this installation will produce finely cut fractions, including a suitable wash oil for benzole recovery.

MARKET PRICES

ALUMINIUM.

Ingots...................... £110 0 0

ANTIMONY.

English....................	£87	0	0
Foreign	87	10	0

BRASS.

Solid Drawn Tubes	lb.	£0	1	0¼
Brazed Tubes	,,	0	1	2¼
Rods Drawn	,,	0	0	10
Wire	,,	0	0	9½
*Extruded Brass Bars	,,	0	0	6¼

COPPER.

Standard Cash	£44	5	0
Electrolytic	51	0	0
Best Selected	48	10	0
Tough....................	48	0	0
Sheets...................	85	0	0
Wire Bars	55	0	0
Ingot Bars	55	0	0
Solid Drawn Tubes .... lb.	0	1	¼
Brazed Tubes ,,	0	1	¼

FERRO ALLOYS.

‡Tungsten Metal Powder, nominal	lb.	£0	4	5½
‡Ferro Tungsten nominal	,,	0	4	4
Ferro Molybdenum	,,		5	7

Ferro Chrome, 60-70% Chr. Basis 60% Chr. 2-ton lots or up.

NOMINAL

2-4% Carbon, scale 12/- per unit	ton	45	5	0
*4-6% Carbon, scale 11/- per unit	,,	38	15	0
6-8% Carbon, scale 10/6 per unit	,,	37	0	0
8-10% Carbon, scale 10/6 per unit	,,	37	0	0

§Ferro Chrome, Specially Refined, broken in small pieces for Crucible Steelwork. Quantities of 1 ton or over. Basis 60% Ch.

Guar. max. 2% Carbon, scale 18/6 per unit	,,	58	0	0
Guar. max. 1% Carbon, scale 14/- per unit	,,	£60	0	0
§Guar. max. 0·5% Carbon, scale 13/- per unit	,,		—	
‡Manganese Metal 97-98% Mn	lb.	0	1	8
‡Metallic Chromium	,,	0	3	7½
§Ferro-Vanadium 50-55% ..	,,	0	14	0
§Spiegel, 18-20%	ton	12	2	6

Ferro Silicon—

Basis 10%, scale 3/- per unit nominal	ton	15	0	0
20/30% basis 25%, scale 3/6 per unit	,,	15	10	0
45/50% basis 45%, scale 5/- per unit	,,	18	0	0
70/80% basis 75% scale 7/- per unit	,,	28	0	0
90/95% basis 90% scale 10/- per unit	,,	40	0	0
§Silico Manganese 65/75% Mn, basis 65% Mn	,,	26	0	0
§Ferro-Carbon Titanium, 15/18% Ti	lb.	0	0	6½
Ferro Phosphorus, 20-25%	ton	35	0	0
§Ferro-Molybdenum, Molyte	lb.	0	5	3
§Calcium Molybdate	,,	0	5	0

FUELS.

Foundry Coke—

S. Wales	£1	18	0
Scotland.................	1	15	0
Durham	1	14	6

Furnace Coke—

Scotland.................	1	9	0
S. Wales.................	1	7	6
Durham	1	9	2

GUN METAL.

*Admiralty Gunmetal Ingots (88 : 10 : 2)	£86	0	0
*Commercial Ingots	70	0	0
*Gunmetal Bars, Tank brand, 1 in. dia. and upwards... lb.	0	1	1
*Cored Bars .... ,,	0	1	3

MANUFACTURED IRON.

Scotland—

Crown Bars	£12	15	0

N.E. Coast—

Rivets		—	
Best Bars	13	5	0
Crown Bars	12	18	0

Lancashire—

Crown Bars	12	15	0
Hoops.................	13	11	0

Midlands—

Crown Bars	12	15	0
Marked Bars		—	
Unmarked Bars		—	
Nut and Bolt Bars	11	0	0
Gas Strip	13	12	0

S. Yorks.—

Best Bars.............	12	5	0
Hoops.................	13	12	6

PHOSPHOR BRONZE.

*Bars, "Tank" brand, 1 in. dia. and upwards—Solid	lb.	£0	1	1
*Cored Bars	,,	0	1	3
†Strip	,,	0	1	0
†Sheet to 10 W.G.	,,	0	1	0½
†Wire	,,	0	1	2
†Rods	,,	0	1	2
†Tubes	,,	0	1	7½
†Castings	,,	0	1	3

†10% Phos. Cop. £30 above B.S.
†15% Phos. Cop. £35 above B.S.
†Phos. Tin (5%) £30 above English Ingots.

PIG IRON.

Scotland—

Hæmatite M/Nos.	£6	4	6
Foundry No. 1	5	12	0
,, No. 3	5	9	6

N.E. Coast—

Hæmatite No. 1	6	4	6
Foundry No. 1	5	11	0
,, No. 3	5	8	0
,, No. 4		—	
Silicon Iron.............		—	
Forge		—	

Midlands—

N. Staffs. Forge No. 4		—	
,, Foundry No. 3 ...	5	10	0

Northants—

Foundry No. 1	5	11	6
Forge No. 4		—	
Foundry No. 3	5	7	6

Derbyshire Forge...........	5	0	0
,, Foundry No. 1...	5	13	0
,, Foundry No. 3....	5	10	0
West Coast Hæmatite	6	4	6
East ,, ,, ...	6	4	6

SWEDISH CHARCOAL IRON AND STEEL.

Pig Iron—

Single welded acid steel billets, ·50% C and up .. Kr. 390

Acid steel wire rods, ·50% C and up ..... Kr. 450 to 495

Rolled charcoal iron bars .. Kr. 510

All Swedish Kronor per British ton f.o.b. Swedish port.

SCRAP METAL.

Copper, Clean		£38	0	0
,, Braziery		35	0	0
,, Wire			—	
Brass		23	0	0
Gun Metal		38	0	0
Zinc		9	0	0
Aluminium Cuttings		72	0	0
Lead		11	10	0

Heavy Steel—

S. Wales.................	3	0	3
Scotland.................	2	19	0
Cleveland	3	1	0

Cast Iron—

Midlands	3	7	0
S. Wales................	3	7	9
Cleveland	3	6	6

Steel Turnings—

Cleveland	2	7	0
Midlands	2	0	3

Cast Iron Borings—

Cleveland	2	0	0
Scotland.................	2	0	0

SPELTER.

G.O.B. Official	£18	0	0
Hard....................	11	10	0
English..................	17	10	0
Empire	17	5	0
Re-melted	16	10	0

STEEL.

Ship, Bridge and Tank Plates—

Scotland....................	£11	10	6
North-East Coast	11	10	6
Midlands	11	13	0
Boiler Plates (Land) Scotland	11	10	6
,, ,, (Marine) ,,		—	
,, ,, (Land) N.E. Coast	11	10	6
,, ,, (Marine) ,,		—	
Angles, Scotland	11	8	0
,, North-East Coast	11	8	0
,, Midlands	11	8	0
Joists	11	8	0
Heavy Rails	10	3	0
Fishplates	14	10	0
Light Rails	12	2	6

Sheffield—

Siemens Acid Billets	11	17	6
Hard Basic	10	7	6
Medium Basic	10	5	0
Soft Basic	10	0	0
Hoops...................	13	11	0

Manchester—

Hoops...................	13	11	0
Scotland, Sheets 24 B.G.	16	2	6

¶HIGH-SPEED TOOL STEEL.

Finished Bars 14% Tungsten...................	lb.	£0	3	0
Finished Bars 18% Tungsten...................	,,	0	3	10

Extras :

Round and Squares, ½ in. to ¼ in..................	0	0	3
Under ¼ in. to ⅛ in.	0	1	0
Round and Squares, 3 in. ..	0	0	4
Flats under 1 in. × ⅛ in. ..	0	0	3
,, ½ in. × ¼ in. ..	0	1	0

TIN.

Standard cash	£272	0	0
English..................	272	10	0

Tin Plates I.C. 20 × 14 box .... £1 11 0/£1 12 0

ZINC.

English Sheets	£30	12	6
Zinc Boiler Plates..........	28	12	6
Battery Plates		—	
Boiler Plates..............		—	

LEAD.

Soft Foreign	£17	5	0
Empire	17	10	0

---

* McKechnie Brothers, Ltd., Dec. 12. † C. Clifford & Sons, Ltd., Dec. 12. ‡ Murex Limited., Dec. 12.
Subject to Market fluctuations. Buyers are advised to send inquiries for current prices when about to place order.

§ Prices ex warehouse, Dec. 12. ¶ The prices fluctuate with the price of Tungsten.

CROTORITE

ALUMINIUM BRONZES

High Tensile Alloys free from Zinc and offering great resistance to corrosion by both Electrolytic and Chemical Action. Their Physical Properties are retained at elevated temperatures. The hardness of the Crotorite IV Alloy can be increased by a suitable Heat Treatment, to resist abrasion in service.

THE MANGANESE BRONZE & BRASS CO., LTD

HANDFORD WORKS. IPSWICH.　　　　Telephone:— IPSWICH 2127

techdesign

METALLURGIA.
Contents.
For DECEMBER, 1939.

ADVERTISERS' ANALYSIS

Acids
Imperial Chemical Industries, Ltd. Imperial Chemical House London, S.W. 1.

Alloys
Addalloy Metal Co. Ltd., 14, Park Lane, Sheffield 10.

Aluminium and its Alloys
Aluminium Union, Limited, The Adelphi, Strand, London, W.C. 2.
Birmabright Ltd.
Earle, Bourne & Co., Ltd., Heath Street South, Birmingham.
High Duty Alloys, Ltd., Trading Estate, Slough.
Wm. Mills, Ltd., Birmingham.
Northern Aluminium Co., Ltd., Bush House, London, W.C. 2.
Priestman, T. J., Ltd., Birmingham.

Anti-Friction Metals
Addalloy Metal Co., Ltd., 14, Park Lane, Sheffield, 10.
Billington & Newton Ltd., Longport.
Earle Bourne & Co., Ltd., Birmingham.
McKechnie Bros., Ltd., Rotton Park St., Birmingham.

Brass and Bronze
Billington & Newton, Ltd., Longport.
Clifford, Chas. and Son, Ltd., Birmingham.
Earle, Bourne & Co., Ltd. Heath Street South, Birmingham.
I.C.I. Metals Ltd., Birmingham.
John Holroyd, Ltd., Rochdale.
Manganese Bronze & Brass Co., Ltd., Handford Works, Ipswich.
McKechnie Bros., Ltd., Rotton Park St., Birmingham.

Casehardening Compounds
Amalgams Co., Ltd., Attercliffe Rd., Sheffield.
Expert Tool & Casehardening Co., Ltd., London, S.W. 19.
G.W.B. Electric Furnaces, Ltd., Belgrove House, Belgrove St., W.C. 1.
I.C.I. Cassel Cyanide.
Kasenit Ltd., Holyrood St., Bermondsey St., London, S.E. 1.

Castings (Iron)
Rudge Littley Ltd., West Bromwich.
Wallwork, H., and Co., Ltd., Roger St., Manchester.

Castings (Non-ferrous)
Birmabright Ltd.
Castalloy Ltd., Holyrood Street, London, S.E. 1.
Magnesium Castings and Products, Ltd., Slough.
Manganese Bronze & Brass Co. Ltd., Handford Works, Ipswich.
William Mills, Limited, Grove St., Birmingham.
Mond Nickel Co., Ltd., Thames House, Millbank, London, S.W. 1.
Northern Aluminium Co. Ltd., Bush House, Aldwych, London, W.C. 2.
Sterling Metals Ltd., Coventry.

CO_2 Recorders
Honeywell Brown, Ltd., Wadsworth Road, Perivale.
Integra Co. Ltd., 183, Broad St., Birmingham, 15.
Cambridge Instrument Co., Ltd., 13, Grosvenor Place, London S.W.1.

Coke-Oven Plant
Gibbon Bros., Ltd., Albert Rd., Middlesbrough.

Electrodes
British Acheson Electrodes, Ltd., Sheffield.

Extruded Rods and Sections
Birmabright Ltd.
Earle Bourne & Co., Ltd., Birmingham.
McKechnie Bros., Ltd., Rotton Park St., Birmingham.
Northern Aluminium Co., Ltd., London.

Fluxes
Addalloy Metal Co. Ltd., 14, Park Lane, Sheffield 10.
Foundry Services Ltd., 285, Long Acre, Nechells, Birmingham, 7.
Imperial Chemical Industries Ltd., Dept. C. 6, Imperial Chemical House, London, S.W. 1.

Forgings
Northern Aluminium Co., Ltd., London.